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An examination of the reduction of effective impervious cover and ecosystem and watershed response

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AN EXAMINATION OF THE REDUCTION OF EFFECTIVE IMPERVIOUS COVER AND ECOSYSTEM AND WATERSHED RESPONSE

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Table of Contents

Acknowledgements iii
Table of Contents v
List of Tables vii
List of Figures viii
List of Acronyms ix
ABSTRACT x
Chapter 1 1
Introduction 1
1.1 Urban Watershed Renewal in Berry Brook 1
1.2 Synthesizing Restoration Efforts 1
1.3 Impervious Cover TMDLs 2
1.4 Stream Integrity 3
1.5 Project Objectives and Methods 4
Chapter 2 6
ABSTRACT 6
2.1 Introduction 9
2.1.1 Urbanization and Impervious Cover 9
2.1.2 Stream Impairment and Restoration 9
2.1.3 Water Quality 11
2.1.4 Hydrology 11
2.1.5 Modeling 12
2.1.6 Effective Impervious Cover 12
2.1.7 Reduction of Effective Impervious Cover 13
2.1.8 Hypothesis and Objectives 14
2.2 Watershed Description 16
2.2.1 Watershed Overview 16
2.2.2 Land Use and Watershed Analyses 17
2.2.3 Background Data 17
2.3 Methods 19
2.3.1 Project Phasing 19
2.3.2 Sampling Locations 20
2.3.3 Sampling Instruments 24
2.3.4 Data Analysis Methods 25

2.3.5 Modeling Methods 30
2.3.6 Modeling Calibration 33
2.4 Results and Discussion 35
2.4.1 Hydrology 35
2.4.2 Water Quality 54
2.4.3 Modeling 68
2.5 Conclusions 77
Chapter 3 82
Conclusions 82
Future Study 84
Limitations 86
References 88
Appendices 92
Appendix A - Berry Brook Watershed 93
Appendix B - Hydrology 98
Appendix C - Water Quality 102
Appendix D - Biota 105
Appendix E – Model 112
Appendix F - LID Drawings 122

List of Tables

Table 2-1: LID Descriptions and Drainage Areas 24
Table 2-2: Analytical Parameters-Direct Runoff Hydrograph 26
Table 2-3: Impervious Cover and Effective Impervious Cover Methods 29
Table 2-4: Analytical Parameters-Water Quality 30
Table 2-5: Non-Parametric Independent Wilcoxon Statistical Analysis of Daily Flow per Watershed Area by Time Period 37
Table 2-6: Non-Parametric Independent Wilcoxon Statistical Analysis of Direct Runoff Hydrograph Parameters by Time Period 41
Table 2-7: Impervious Cover and Effective Impervious Cover Results by Location 51
Table 2-8: Watershed %EIC by Location 51
Table 2-9: Non-Parametric Independent Wilcoxon Exact Statistical Analysis of Storm Event Water Quality by Time Period 56
Table 2-10: Non-Parametric Independent Wilcoxon Exact Statistical Analysis of Storm Event Pollutant Loads by Time Period 59
Table 2-11: Upper Watershed (Roosevelt, DA = 46.4 acres) Water Quality EMC Summary Statistics 65
Table 2-12: Lower Watershed (Station, DA = 184.8 acres) Water Quality EMC Summary Statistics 65
Table 2-13: Upper Watershed (Roosevelt, DA = 46.4 acres) Water Quality Pollutant Load Summary Statistics 66
Table 2-14: Lower Watershed (Station, DA = 184.8 acres) Water Quality Pollutant Load Summary Statistics 66
Table 2-15: Model Results-Design Storm 69
Table 2-16: Model Results- 20 Year Long Term Simulation 72
Table 2-17: Non-Parametric Matched Pair Wilcoxon Signed Rank Analysis of Storm Event Volume and Peak by Modeled Scenario 73

List of Figures

Figure 1-1: Methodology Overview 5
Figure 2-1: Berry Brook Watershed Dover, NH - Delineation and Monitoring Locations 22
Figure 2-2: Berry Brook Subwatershed Delineations and LID Locations 23
Figure 2-3: PCSWMM Berry Brook Model 33
Figure 2-4: Average Daily Area Weighted Flow Comparison of Berry Brook-Lower Watershed (Station, DA = 184.8 acres) and Isinglass River (DA = 73.6 sq. miles) 38
Figure 2-5: Flow Duration Curve for Average Daily Area Weighted Flow Comparison of Berry Brook-Lower Watershed (Station, DA = 184.8 acres) and Isinglass River (DA = 73.6 sq. miles) for Pre_{LID} (86days) and $Post_{LID}$ (74days) 39
Figure 2-6: Box Plot Legend 41
Figure 2-7: Direct Runoff Unit Hydrograph Parameters at Upper Watershed (Roosevelt, DA = 46.4 acres) for 19 Storms Pre_{LID} (06/11-10/11) and 9 Storms $Post_{LID}$ (10/12-12/12) 42
Figure 2-8: Direct Runoff Unit Hydrograph Parameters at Lower Watershed (Station, DA = 184.8 acres) for 17 Storms Pre_{LID} (07/11-10/11) and 11 Storms $Post_{LID}$ (10/12-12/12) 45
Figure 2-9: Rainfall Runoff at BB-Lower Watershed (Station, DA = 184.8 acres) by Time Period 48
Figure 2-10: Rainfall-Runoff at BB-Upper Watershed (Roosevelt, DA = 46.4 acres) by Time Period 52
Figure 2-11: Storm Event Water Quality at Upper Watershed (Roosevelt, DA = 46.4 acres) for 10 Storms Pre_{LID} (06/11-10/11) and 5 Storms $Post_{LID}$ (10/12-12/12) 57
Figure 2-12: Storm Event Pollutant Loads at Upper Watershed (Roosevelt, DA = 46.4 acres) for 6 Storms Pre_{LID} (06/11-10/11) and 4 Storms $Post_{LID}$ (10/12-12/12) 60
Figure 2-13: Storm Event Water Quality at Lower Watershed (Station, DA = 184.8 acres) for 11 Storms Pre_{LID} (06/11-10/11) and 4 Storms $Post_{LID}$ (10/12-12/12) 62
Figure 2-14: Storm Event Pollutant Loads at Lower Watershed (Station, DA = 184.8 acres) for 6 Storms Pre_{LID} (06/11-10/11) and 4 Storms $Post_{LID}$ (10/12-12/12) 67
Figure 2-15: Design Storm Modeled Hydrograph 70
Figure 2-16: Design Storm Modeled Pollutograph 70
Figure 2-17: Modeled Scenarios of Storm Event Peak and Volume by Model and Binned Rainfall Depths 74
Figure 2-18: Measured and Modeled Storm Event Median Parameter Response by Field Measured Watershed %EIC 76

List of Acronyms

BMP-Best Management Practices for stormwater

LID-Low Impact Development stormwater practices

Pre_{LID} -period of monitoring prior to LID implementation

$Post_{LID}$ – period of monitoring after LID implementation

IC_{pre} -mapped impervious cover during pre_{LID}

IC_{post} –impervious cover during $post_{LID}$

EIC_{pre} -field measured effective impervious cover during pre_{LID}

$EIC_{pre\text{-}Sutherland}$ – Sutherland's method for determining effective impervious cover during pre_{LID}

$EIC_{pre\text{-}USGS}$ – USGS method for determining effective impervious cover during pre_{LID}

EIC_{post} –field measured effective impervious cover during $post_{LID}$

$EIC_{post\text{-}Sutherland}$ – Sutherland's method for determining effective impervious cover during $post_{LID}$

$EIC_{post\text{-}EPA}$ – EPA method for determining effective impervious cover during $post_{LID}$

$EIC_{post\text{-}WQV}$ – Hlas, Roseen method for determining effective impervious cover during $post_{LID}$

PCSWMM – PC software for stormwater management, wastewater and watershed modeling

Pre_{model} – PCSWMM model of pre_{LID} conditions

LID_{model} – PCSWMM model of $post_{LID}$ conditions represented by structural LID systems

EIC_{model} – PCSWMM model of $post_{LID}$ conditions represented by EIC adjustments

Ia_{pre} – Initial abstraction during pre_{LID}

Ia_{post} – Initial abstraction during $post_{LID}$

ABSTRACT

AN EXAMINATION OF THE REDUCTION OF EFFECTIVE IMPERVIOUS COVER AND ECOSYSTEM AND WATERSHED RESPONSE

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This study examined the reduction of effective impervious cover (EIC) and watershed response by Low Impact Development (LID) and stream restoration efforts. The Berry Brook Watershed Renewal Project consisted of day lighting approximately 1,100 feet of stream and installation of 13 LID systems for a combined impervious area treatment of 20.7 acres on a 185 acre watershed. Watershed response was measured and modeled by hydrologic and water quality parameters.

Hydrologic daily flow analysis revealed that there was a significant decrease in average, maximum and minimum flows between pre_{LID} and $post_{LID}$ periods in the direction of a lesser developed watershed (p-value: <0.0001). Analysis of direct runoff unit hydrographs for mean, median, standard deviation, skew, kurtosis and peak at two locations indicated there was no statistically significant difference between pre_{LID} and $post_{LID}$. This indicates that for the period of monitoring LID implementation and stream restoration improvements were not statistically detectable in direct runoff unit hydrograph parameters. A 46% decrease in median runoff volumes was observed at the watershed terminal $post_{LID}$ (p-value: 0.11). IC_{pre} mapped impervious cover was calculated to be 30.1%. Pre_{LID} EIC was determined by three methods that had excellent

agreement: direct calculation of runoff depth vs. rainfall (15.6%), Sutherland (16.5%) and USGS (16.5%). $Post_{LID}$ EIC values were determined by three methods and had modest agreement: runoff depth vs. rainfall (11.7%), EPA method (13.8%), EIC disconnection (8.2%) and a proposed method based on water quality volume treated (10.8%).

Water quality concentration improvements were observed for TSS, Zn and TP where storm event median values were reduced by (59%, 50% and 78%) (p-values: 0.018, 0.026, 0.002). At the watershed scale a comparison of pollutant loads between pre_{LID} and $post_{LID}$ time periods showed significant improvements in all analyzed parameters, median reductions of TSS by 95% (p-value: 0.033), TP by 97% (p-value: 0.010), and TN 80% (p-value: 0.130).

Three PCSWMM watershed models were built to examine the long-term response of restoration efforts. A Pre_{model} represented the watershed prior to improvements. Two other models were constructed to simulate the watershed post-construction with LID and stream restoration improvements. One method simulated LID implementation at the system scale (LID_{model}). The other method also simulated the watershed post-construction of LID but at the watershed scale with the use of EIC (EIC_{model}). A 20-year rainfall runoff simulation of the LID conditions showed reductions in runoff volume by 18% and pollutant load reductions of TSS by 28%, TN by 15%, and TP by 7%. LID_{model} runoff volumes and peaks were not statistically different from the Pre_{model} at storm depths of 1 inch or greater. The EIC_{model} and LID_{model} had excellent agreement over the 20 year simulation and were not significantly different in runoff volumes. This indicates that modeling LID implementation as EIC reduction may be an acceptable method for determining runoff volume.

Chapter 1

Introduction

1.1 Urban Watershed Renewal in Berry Brook

The Berry Brook Watershed Renewal Project provided a unique opportunity to implement Low Impact Development (LID) practices and examine a relationship between the reduction of effective impervious cover (EIC) and ecosystem response as measured by abiotic water quality parameters, hydrology and lotic biota. The goal of the research project was to examine watershed response within the context of restoration efforts. The impervious cover model (ICM) was originally formulated to diagnose the severity of stream issues in urban subwatersheds, the future challenge is to test the hypothesis that the ICM can predict stream response by managing IC (Schueler et al. 2009). A USGS study "Effects of urbanization on stream quality at selected sites in the seacoast region in New Hampshire, 2001-03" identified impaired macroinvertebrate communities in Berry Brook. As a result of this study Berry Brook was listed on the EPA's 303d list by the New Hampshire Department of Environmental Services (NHDES) as an impaired water, due to a lack of aquatic life support. Stormwater runoff was targeted as one of the sources for aquatic life impairment.

1.2 Synthesizing Restoration Efforts

Roughly 44% of assessed streams and rivers in the U.S. are impaired for one or more uses (EPA 2009). Impairments include: aquatic life support, fish consumption, primary and secondary contact and drinking water supply. Primary stressors behind impairments include: pathogens, habitat alterations, nutrients, metals, sediments, and flow alteration (EPA 2009). Many of the pollutant sources can be attributed to watershed urbanization and stormwater runoff.

It is estimated that from 1990 to 2003 U.S. restoration efforts have exceeded $15 billion (Bernhardt et al. 2005). Many of the smaller scale projects, those involving about 1 km of stream restoration or less were not designed with post improvement monitoring and evaluation (Bernhardt et al. 2005). Throughout the U.S. there is a need for continuing watershed and stream restoration efforts based on the recent findings of impairments; furthermore it is essential that we gain an understanding of the responses of these ecosystems to restoration practices. Not all restoration projects are created equal, for example objectives can vary from improving water quality to addressing fish passage. A common communication tool between watershed planners and engineers would prove to be useful in describing watershed characteristics and restoration activities. Statements of restoration goals, objectives and criteria for success are a necessity. Synthesizing this type of information will optimize future allocation of efforts.

1.3 Impervious Cover TMDLs

While many watershed metrics can be examined, impervious cover is one that is becoming a surrogate for total maximum daily load (TMDL) (CTDEP 2007; MEDEP 2012). Effective impervious cover is known to negatively affect the hydrologic cycle (Smith 2002). Impervious cover is also a quantifiable value that can be used as a convenient management tool for watershed planners.

Currently, Maine Department of Environmental Protection (MDEP) is developing a TMDL designed to target impervious cover reduction for waters on the 303d list. The IC TMDL is to be used as a surrogate while success is measured by meeting aquatic life criteria (MEDEP 2012). The IC targets have been based on tiered aquatic life categories and were developed using available macroinvertebrate metrics that have been correlated to impervious cover threshold percentages of 6-15% (MEDEP 2012). The Connecticut Department of Environmental Protection (CTDEP) has taken a similar approach for Eagleville Brook in Mansfield, CT and implemented a 12% IC TMDL target (CTDEP 2007). This threshold has been chosen based the impervious cover model that indicates 10% as the region between sensitive and impacted (Schueler et al. 2009). CTDEP does recognize that IC may not be the only reason for aquatic life impairment but if stormwater is recognized as a stressor %IC will be used as the surrogate (CTDEP 2007).

1.4 Stream Integrity

Although stream integrity can be described by many parameters, macroinvertebrate diversity and richness has commonly been used as an indicator of stream health (Schueler 1994; Schueler et al. 2009). Studies have shown that macroinvertebrate diversity is negatively correlated with watershed imperviousness once 10-15% has been exceeded (Deacon et al. 2005; Klein 1979). In New Hampshire, macroinvertebrate abundance and taxa richness were found to be generally higher in streams with forested watersheds (Deacon et al. 2005). Watersheds with impervious cover greater than 14% showed reduced water quality, habitat and biological condition scores (Deacon et al. 2005).

1.5 Project Objectives and Methods

Overall, this study examined the reduction of effective impervious cover (EIC) by LID and stream restoration activities with respect to hydrology, water quality and biota response. Analysis of land use cover and the reduction of EIC were compared with field measured, empirical and proposed methods. A calibrated watershed model was built to identify long-term hydrologic and water quality response as a result of LID and stream restoration activities.

This study consisted of four phases to address project objectives: 1) Pre_{LID} monitoring, 2) LID-implementation (construction), 3) $Post_{LID}$ monitoring, 4) Data analysis and watershed model (Figure 1-1). The project objectives were tested by comparing monitoring data from Pre_{LID} and $Post_{LID}$ phases. This comparison included both quantitative and qualitative analysis to assess parameter response by time period. Monitored hydrologic and water quality parameters were chosen based on common pollutants from sources of stormwater runoff and urbanization. Monitoring locations were assigned to represent hydrologic divides at subwatershed scales. Multiple monitoring locations also helped in identifying parameter response as a result of specific improvements. Berry Brook monitoring overview identifies all of the collected parameters by time period and location within the watershed (Appendix A - Berry Brook Watershed).

Chapter 2 of this thesis is written as a separate paper that examines the water quality and hydrological response as a result of the reduction of effective impervious cover by LID implementation and watershed improvements Chapter 3 is intended provide concluding remarks and comment on the biotic and water quality results not presented in Chapter 2.

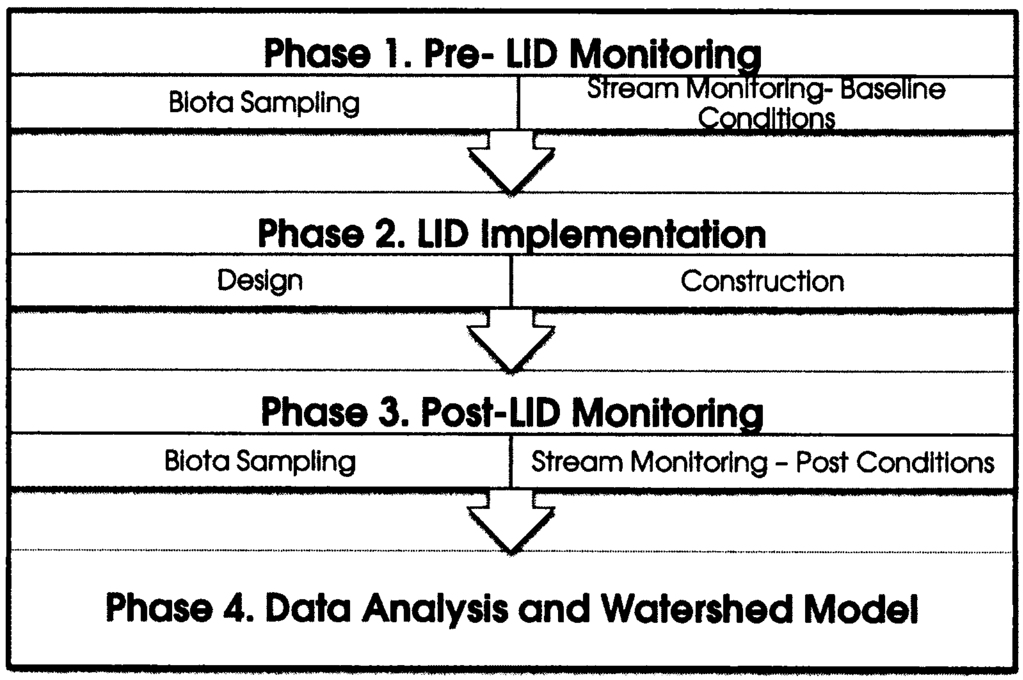

Figure 1-1: Methodology Overview

Chapter 2

ABSTRACT

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This study examined the reduction of effective impervious cover (EIC) and watershed response by Low Impact Development (LID) and stream restoration efforts. The Berry Brook Watershed Renewal Project consisted of day lighting approximately 1,100 feet of stream and installation of 13 LID systems for a combined impervious area treatment of 20.7 acres on a 185 acre watershed. Watershed response was measured and modeled by hydrologic and water quality parameters.

Hydrologic daily flow analysis revealed that there was a significant decrease in average, maximum and minimum flows between pre_{LID} and $post_{LID}$ periods in the direction of a lesser developed watershed (p-value: <0.0001). Analysis of direct runoff unit hydrographs for mean, median, standard deviation, skew, kurtosis and peak at two locations indicated there was no statistically significant difference between pre_{LID} and $post_{LID}$. This indicates that for the period of monitoring LID implementation and stream restoration improvements were not statistically detectible in direct runoff unit hydrograph parameters. A

46% decrease in median runoff volumes was observed at the watershed terminal $post_{LID}$ (p-value: 0.11). IC_{pre} mapped impervious cover was calculated to be 30.1%. Pre_{LID} EIC was determined by three methods that had excellent agreement: direct calculation of runoff depth vs. rainfall (15.6%), Sutherland (16.5%) and USGS (16.5%). $Post_{LID}$ EIC values were determined by three methods and had modest agreement: runoff depth vs. rainfall (11.7%), EPA method (13.8%), EIC disconnection (8.2%) and a proposed method based on water quality volume treated (10.8%).

Water quality concentration improvements were observed for TSS, Zn and TP where storm event median values were reduced by (59%, 50% and 78%) (p-values: 0.018, 0.026, 0.002). At the watershed scale a comparison of pollutant loads between pre_{LID} and $post_{LID}$ time periods showed significant improvements in all analyzed parameters, median reductions of TSS by 95% (p-value: 0.033), TP by 97% (p-value: 0.010), and TN 80% (p-value: 0.130).

Three PCSWMM watershed models were built to examine the long-term response of restoration efforts. A Pre_{model} represented the watershed prior to improvements. Two other models were constructed to simulate the watershed post-construction with LID and stream restoration improvements. One method simulated LID implementation at the system scale (LID_{model}). The other method also simulated the watershed post-construction of LID but at the watershed scale with the use of EIC (EIC_{model}). A 20-year rainfall runoff simulation of the LID conditions showed reductions in runoff volume by 18% and pollutant load reductions of TSS by 28%, TN by 15%, and TP by 7%. LID_{model} runoff volumes and peaks were not statistically different from the Pre_{model} at storm depths of 1 inch or greater. The EIC_{model} and LID_{model} had excellent agreement over the 20 year simulation and were not significantly different in runoff volumes. This indicates that modeling LID implementation as EIC reduction may be an acceptable method for determining runoff volume.

2.1 Introduction

2.1.1 Urbanization and Impervious Cover

Urbanization of U.S. watersheds has led to negative effects and impairments in stream ecosystems and in particular water quality, stream biota and hydrologic alterations (Arnold and Gibbons 1996; Deacon et al. 2005; Paul and Meyer 2008; Roy et al. 2003; Wang et al. 2001). In New Hampshire, local studies have examined impervious cover as a measure of urban development and declines in aquatic integrity (Deacon et al. 2005). Studies have shown that stormwater runoff from impervious surfaces has led to higher peak discharges and contaminant loads to receiving water bodies (Booth et al. 2002; Booth and Jackson 1997; CWP 2003; Klein 1979). A 2001 study found that for 16 land-use types in Wisconsin watersheds connected impervious cover was the best descriptor of variation in fish community attributes and stream base flows (Wang, Lyons et al). Schueler (2009) states that "imperviousness is one of the few variables that can be explicitly quantified, managed and controlled at each stage of land development". The impervious cover model (ICM) identifies stream integrity as a function of watershed impervious cover (Schueler et al. 2009). Numerous studies have identified 10-14% impervious cover as a threshold where stream impairments become marked (Booth and Jackson 1997; CWP 2003; Deacon et al. 2005; Klein 1979; Schueler 1994; Schueler et al. 2009).

2.1.2 Stream Impairment and Restoration

In 2009, United States Environmental Protection Agency (USEPA) reported that 44% of rivers and streams were listed as impaired for one or more uses based on assessment of 16% of U.S. streams and rivers (EPA 2009). It is estimated that from 1990 to 2003 U.S. restoration efforts have exceeded $15 billion (Bernhardt et al. 2005). Most watershed projects are of small scale and little or no information is readily accessible for the implementation and success of these projects (Bernhardt et al. 2005). Bernhardt, Palmer et al. (2005) found that only about 10% of restoration projects indicated assessments or monitoring after restoration, furthermore most of the projects (~3700) were not designed to evaluate the effectiveness of restoration activities. Restoration projects can be classified into four categories: stormwater management, bank stabilization, channel reconfiguration and grade control, and riparian replanting and management (Bernhardt and Palmer 2007). Early watershed restoration work suggests that after extensive stormwater retrofit and habitat restoration, partial biological diversity can be re-established (Schueler 1994). Selego, Rose et al. (2012) observed a significant improvement in the macroinvertebrate community less than three months after completion of in-stream and stream-bank restoration techniques. Richardson, Flanagan et al. (2011) found that a multi-phased restoration including stream restoration and re-contouring of wetlands improved water quality for nutrients and coliform bacteria along with increased sediment retention.

Although the ICM was originally formulated to diagnose the severity of stream issues in urban subwatersheds, the future challenge is to test the hypothesis that the ICM can predict stream response by managing IC (Schueler et al. 2009). The states of Connecticut and Maine have taken initiative to address their water quality issues using %IC as a surrogate for Total Maximum

Daily Load (TMDL)(CTDEP 2007; MEDEP 2012). This approach is applied when stormwater runoff is found to be the primary source of pollutant stressors within the stream (CTDEP 2007).

2.1.3 Water Quality

Urban runoff contains pollutants that contribute to degradation of water quality (Wang et al. 2001). Leading pollutants of impaired streams include: pathogens, oxygen limiting nutrients, metals and sediments (EPA 2009). Urban watersheds have been shown to contribute contaminant concentrations up to several orders of magnitude greater than pre-development conditions, including nutrients and bacteria (Deacon et al. 2005). While abiotic parameters do not necessarily reflect biotic health, changes in parameter concentrations can be related to biotic response (Brabec et al. 2002).

2.1.4 Hydrology

Urbanization and impervious surfaces limit the amount of infiltration and alter the delivery of stormwater runoff to receiving waters (Richardson 2011). Conventional urban developments modify the natural drainage system to convey stormwater as quickly as possible to the receiving waters (Booth and Jackson 1997). These stormwater conveyance systems increase peak flows which can cause severe bank erosion and alteration to geomorphology of the streams. Due to the altered hydrology it becomes increasingly difficult to maintain habitat integrity (Booth and Jackson 1997; Richardson 2011). Furthermore, connected impervious cover has been found to decrease base flows in areas of moderately to heavily urbanized watersheds (Wang et al. 2001).

2.1.5 Modeling

The EPA Storm Water Management Model (SWMM) software was originally developed in 1971 and is used for rainfall-runoff simulation for single or long-term continuous events (Rossman 2004). The software is able to predict runoff quantity and quality from primarily urban watersheds (Rossman 2004). SWMM has been applied in many studies to predict and manage stormwater runoff, flood scenarios, BMP and LID effectiveness, and combined sewer overflow applications. The USGS used this software for the "Measured and Simulated Runoff to the Lower Charles River, Massachusetts, October 1999-September 2000" where a calibrated model was used to develop management plans for the Charles River based on combined sewer overflows (CSOs) and non-CSO stormwater. Studies have also used SWMM to understand the impacts of watershed imperviousness on stormwater systems and in particular the application of effective impervious cover (Guo et al. 2010; Lee and Heaney 2003). The recent addition of the LID platform has been used to gain an understanding of impervious cover and LID performance at the system scale (Guo et al. 2010). This study provides a unique opportunity to measure and model LID performance and stream restoration at the watershed scale.

2.1.6 Effective Impervious Cover

Impervious cover provides a common index between watershed planners, stormwater engineers, water quality regulators and stream ecologists (Arnold and Gibbons 1996; Schueler et al. 2009). Although IC is a widely used term, measuring and describing various types is not always consistently presented. Methods of determining IC include aerial photography, remote sensing, and physical observation. From these methods, the IC is classified by type and degree of connection. Effective or directly connected impervious cover (EIC or DCIC) is the area that is hydraulically connected to the receiving body of water by means of continuous paved surfaces, gutters, drain pipes or other conventional conveyance and detention structures that do not reduce runoff volume (EPA 2011). For the purpose of this paper EIC is defined as directly connected IC and is interchangeable with DCIC. Degree of watershed EIC varies by method and is subject to GIS discretization, empirical relationships or field assessments (Alley and Veenhuis 1983; Han and Burian 2009; Sutherland 1995; UNHSC 2012a). Sutherland (1995) described empirical equations that may be used to calculate EIC from total watershed IC based on land use. Sutherland's methods along with other empirical equations were tested in this study by direct field measurements.

2.1.7 Reduction of Effective Impervious Cover

Reduction of EIC can be achieved by Best Management Practices (BMPs) that reduce runoff volume (EPA 2011). Currently stormwater practices that achieve pollutant removal and reduce peak flows but lack in volume reduction are not considered for EIC reduction (EPA 2011). Low Impact Development (LID) systems such as subsurface gravel wetlands receive little or no credit for EIC reduction but these systems can significantly reduce pollutant loads, and peak flows and lag times to the receiving water bodies (Hood et al. 2007; Roseen et al. 2009). In urban watershed renewal where retrofits are common, restoring infiltration and increasing volume reduction may be difficult. For this reason there is a need to further examine EIC reduction as a function of multiple parameters that can be altered by watershed improvements. Currently, the EPA method of calculating EIC reduction uses a BMP "disconnection" multiplier that is generated based on typical values of stormwater volume reduction that vary by BMP system (EPA 2011). From this calculation it is possible to track the disconnection or reduction of EIC throughout a watershed by implementation of LID or BMP practices.

2.1.8 Hypothesis and Objectives

The Berry Brook Watershed Renewal Project provided a unique opportunity to implement Low Impact Development (LID) practices and examine a relationship between the reduction of EIC and ecosystem response as measured by abiotic water quality and hydrologic parameters. The purpose of the research project is to examine watershed response within the context of restoration efforts. The hypothesis is that reduction of effective impervious cover and watershed improvements will lead to improved water quality and hydrology in the context of reduced pollutant loads and runoff volume.

Project objectives:

a. Examine the relationship of effective impervious cover reduction and watershed improvements with respect to changes in water quality.
b. Examine the relationship of effective impervious cover reduction and watershed improvements with respect to changes in hydrologic response.

c. Examine land use cover by field measured, empirical, and proposed methods.

d. Create a calibrated watershed model that can be predictive of effective impervious cover reduction, water quality and hydrologic response at the watershed scale as a result of LID and stream restoration activities.

2.2 Watershed Description

2.2.1 Watershed Overview

Berry Brook Watershed of Dover, NH consists of 185 acres, 30% of which are classified as impervious cover by GIS delineation. Berry Brook is a first order headwater stream that is approximately 1.2 stream miles in length and is a tributary to the Cocheco River. The average slope of Berry Brook is approximately 1.5%. Dover climate is typical of New England, average yearly precipitation is 46 inches, summer and winter mean temperatures are 69°F and 27°F. The watershed hydrologic soil group distributions by type include: A (37%), B (4%), C (59%) and D (0.9%) based on Web Soil Survey by the National Resources Conservation Service (NRCS).

The relatively small scale of the Berry Brook Watershed enables an examination of the impact of major reductions of effective impervious cover on water quality and hydrologic parameters. In larger watersheds, cumulative measurable benefits from stormwater management may not be realized for decades. Determining the effect and impact of urban watershed renewal efforts can be extremely challenging due to the large scale of a watershed in relation to specific targeted improvements. Berry Brook Watershed represents a typical urban residential environment making it an ideal location to study the project objectives. Furthermore, the watershed underwent significant efforts to reduce effective impervious cover by implementation of LID and stream restoration to minimize impacts of stormwater runoff and improve habitat integrity. The watershed improvements provided an opportunity to monitor the changes that Berry Brook experiences.

2.2.2 Land Use and Watershed Analyses

GIS land use and impervious cover classification of the Berry Brook watershed was used to support this research. The impervious cover analysis was completed by the UNH Complex Systems Research Center using a 1 foot resolution aerial image and cutting polygons around specific land cover types (Appendix A - Berry Brook Watershed). This data helped in targeting EIC reduction by type and location.

Predominant land use within the Berry Brook Watershed includes: residential single and multifamily (64%), forested land (16%), roads (7%), commercial (6%) and educational (4.8%) (Appendix A - Berry Brook Watershed.) Impervious cover in the watershed was subcategorized into: asphalt roads, asphalt driveways, compacted gravel/soil, asphalt parking, rooftops, other asphalt and other built. Of the 185 acres, 55.6 acres (~30%) was estimated as impervious cover. Asphalt roads, driveways and rooftops were the largest contributors to the impervious cover. By watershed area pervious cover including lawns and forested land account for 51% and 16%.

2.2.3 Background Data

Multiple reference sources were considered including previous work in this location by the USGS and NHDES. These studies provided baseline information that was used to assess impairments and potential sources. The USGS study, "Effects of Urbanization on Stream Quality at Selected Site in the Seacoast

Region in New Hampshire, 2001-03" found that Berry Brook had among the lowest scores in biological condition and water quality/habitat. Findings from a NHDES study in 2005 listed Berry Brook for impairment of recreational use based on high bacteria concentrations. Berry Brook is currently listed on the 303d list by the NHDES as an impaired water due to a lack of aquatic life support. Based on the background studies, stormwater runoff and the associated high iron and bacteria concentrations were considered the leading causes for impairment in Berry Brook.

The Isinglass and Oyster River USGS gaged reference reaches were selected to provide nearby hydrologic data. A comparison of daily flow characteristics between Berry Brook and the references reaches was used to understand climatic shifts between time periods. It was also important to use reference watersheds where land use was relatively unaltered during the period of monitoring. The Oyster River gage (latitude 43°08'55"N, longitude 70°57'56"W-NAD27) is located about 8.2 miles from Berry Brook and has a watershed area of 12.1 sq. miles. Estimated impervious cover based on the entire Oyster River Watershed is approximately 11.1% (UNH 2012). This may be an over approximation considering that the USGS gage is located well above the Durham area that contributes a significant portion of impervious cover. The Isinglass River gage (latitude 43°14'05"N, longitude 70°57'25"W-NAD27) is a tributary to the Cocheco River similarly to Berry Brook and is located about 5 miles from the Berry Brook Watershed. The Isinglass watershed area is 73.6 sq. miles of rural and forested land use, impervious cover is approximately 6.0% (UNH 2012).

2.3 Methods

Based on project objectives this study examined the comparison of storm event hydrologic and water quality parameters prior to and after LID implementation and watershed improvements. Monitored water quality parameters were chosen based on typical stormwater runoff pollutants. Discharge was monitored on a real-time basis and provided sufficient data to examine daily hydrology, direct runoff unit hydrograph distributions, and runoff volumes. It was hypothesized that all monitored parameters could be affected by LID implementation and watershed improvement efforts.

2.3.1 Project Phasing

Phase 1 - Pre_{LID}:

The first phase of the project consisted of data collection and monitoring Berry Brook in its existing condition. Data collection prior to watershed improvements provided a baseline for the parameters of interest. Pre_{LID} monitoring occurred during July-October 2011 (~123 days).

Phase 2 - Construction:

The second phase of the project was LID implementation and watershed improvement efforts. For the context of this study LIDs are referred to as green infrastructure which includes systems such as tree filters and bioretention systems. The UNHSC designed the LID systems to be integrated into the existing urban landscape (Figure 2-2, Appendix F - LID Drawings). Most of the retrofit LID systems were designed with a 1 inch water quality volume criteria defined by the New Hampshire Stormwater Manual (Table 2-1). The sub-surface gravel wetland which was the largest LID by area and volume treated was sized at a 0.27 inch water quality volume due to horizontal and vertical constraints.

Constructed LID systems included 3 swales, 6 bioretention systems, a sub-surface gravel wetland, a tree filter, and raingarden for a combined treated impervious area of 20.7 acres (Figure 2-2, Table 2-1). Other watershed improvements included stream restoration which day lighted approximately 1,100 feet of stream and a wetland expansion of ~0.6 acres in the upper watershed. It should be noted that the swale construction in the upper watershed provided a direct connection between two of the upper subwatersheds (Page Ave and Crescent) and the newly constructed wetland (Table 2-1, Figure 2-2). Prior to construction the described subcatchment outlets terminated prior to Berry Brook.

This phase continued until all construction efforts were completed. The construction phase occurred for about one year beginning in October of 2011 and ending in October of 2012.

Phase 3 - Post$_{LID}$: The third phase or post$_{LID}$ monitoring began shortly after all of the proposed LID systems and watershed improvements were completed. Monitoring and data collection practices during this phase paralleled and replicated those completed in Phase 1. Post$_{LID}$ monitoring occurred during October-December 2012 (~74 days).

2.3.2 Sampling Locations

In order to quantify and relate effective impervious cover reduction and watershed improvements with respect to stream parameters it was necessary to locate monitoring equipment based on subwatershed scales. Locations were selected within the watershed where substantial reductions in effective impervious cover were expected (Figure 2-1, Figure 2-2)

Upper Watershed - Roosevelt Ave (43°12'42"N, 70°52'46"W-NAD 83)

Berry Brook flows underneath Roosevelt Ave, which is located just south of the old Dover Water Treatment Facility (Figure 2-1). Drainage area above this monitoring location is 46.4 acres and degree of IC is 18.2 acres or 39.4%. Watershed area above this location underwent significant LID implementation and stream restoration activities. The stream restoration activities day lighted approximately 1,100 feet of stream that was previously flowing through a culvert. LID implementation included a bioretention system, a sub-surface gravel wetland, two swales, a surface wetland expansion and building/road removal for a combined LID treatment of 14.2 impervious acres (Table 2-1, Figure 2-2). Remaining untreated IC was 4.1 acres or 8.8% in the upper watershed.

Lower Watershed - Station Drive (43°12'07"N, 70°52'53"W-NAD 83)

Station Drive, a multi-unit housing complex south of Sixth Street is the watershed terminal monitoring location in Berry Brook before it enters the Cocheco River (Figure 2-1). At this location the entire 185 acre (30.1% IC) watershed is contributing to the stream. This location was affected by the same restoration activities as explained above Roosevelt in addition to a tree filter, 5 bioretention systems, a swale and a raingarden for a combined total watershed treatment of 6.5 impervious acres in the lower watershed and 14.2 impervious acres in the upper (Table 2-1, Figure 2-2).

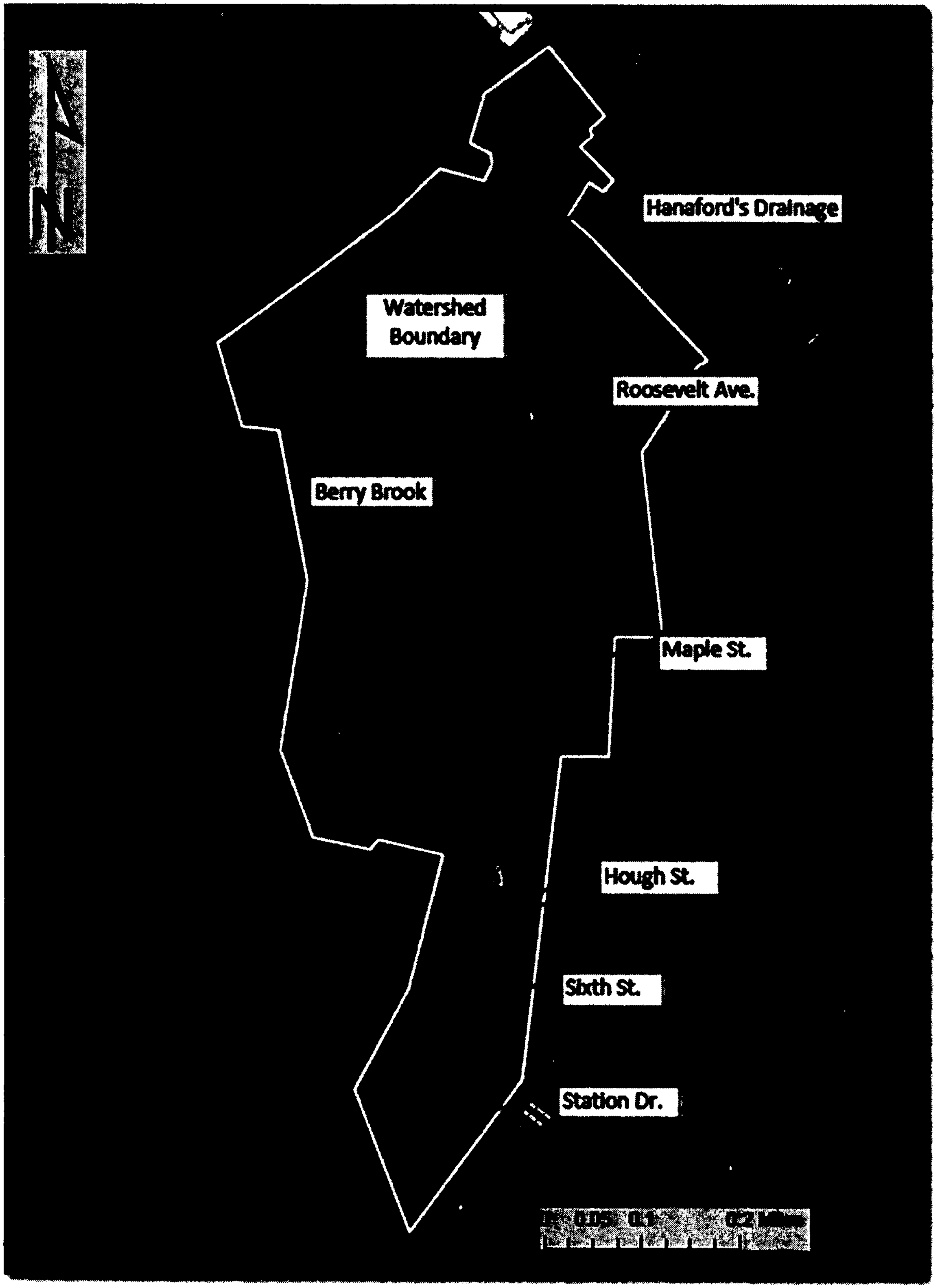


Figure 2-1: Berry Brook Watershed Dover, NH - Delineation and Monitoring Locations

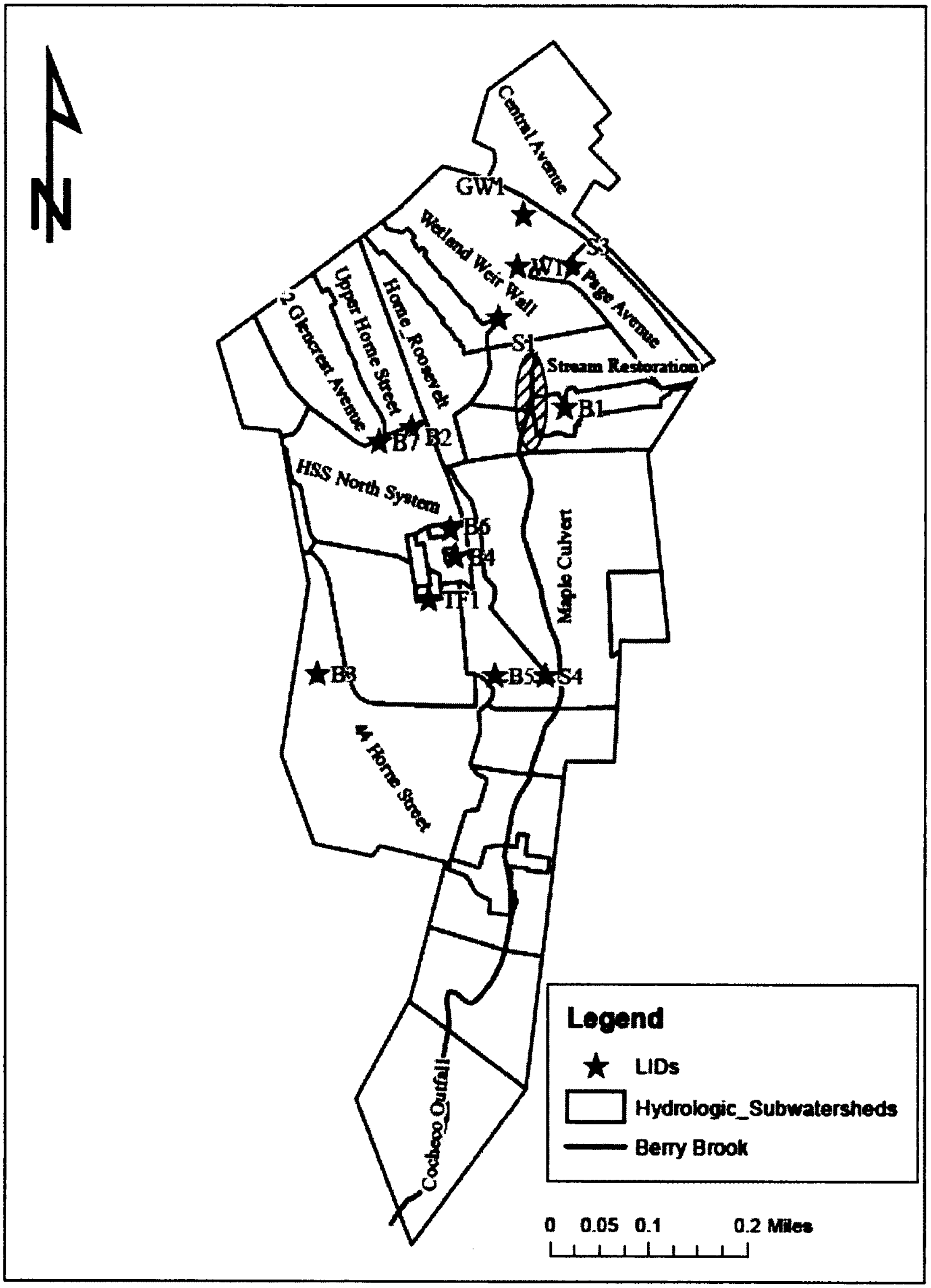


Figure 2-2: Berry Brook Subwatershed Delineations and LID Locations

Table 2-1: LID Descriptions and Drainage Areas

LID No.	Description	DA (acres)	IC (%)
S1 -> W1	Crescent-Swale to Wetland	2.97	45.1
S3 -> W1	Page-Swale to Wetland	5.23	36.0
S4+B5	Snow-Swale and Bioretention	4.16	37.6
B1	Lowell-Bioretention	2.59	42.5
B2	Upper Horne-Bioretention	7.53	21.1
B3	Hillcrest-Raingarden	0.02	98.3
B4	Horne School-Bioretention2	0.11	64.0
B6	Horne Street School-Bioretention1	0.15	100.0
B7	Glencrest- Bioretention	6.81	33.2
TF1	Horne Street School-Tree Filter	0.33	99.5
GW1	Central-Gravel Wetland	11.00	86.8

2.3.3 Sampling Instruments

Aqua Troll 200 probes manufactured by In-Situ Inc. were used to monitor in stream water depths. Data was recorded every 15 minutes during the preLID monitoring period and at a 5 minute interval during postLID. The change in intervals was made to increase accuracy and data points on the rising limb of the hydrographs during smaller storms.

A Marsh McBirney Current Meter was used to measure stream velocity. Mean velocities were measured by the six-tenths-depth-method and discharge was computed using the midsection method (USBR 1975). A power function was fitted to the stage-discharge measurements to compute flows.

ISCO Portable Samplers manufactured by Teledyne ISCO were used for composite stormwater sample collection. The samples were sent to Absolute Resource Associates for analysis of pollutant concentrations.

2.3.4 Data Analysis Methods

Hydrology

The observed Berry Brook hydrology data was analyzed on a daily and storm event basis for the pre$_{UD}$ (July-October 2011) and post$_{UD}$ (October-December 2012) time periods. Many of the tested hydrologic parameters were found to have highly non-normal distributions and therefore non-parametric statistical tests were performed on the data. All statistical tests were performed with JMP Pro 10 Software by SAS Institute Inc. Statistical differences were determined at an alpha of 0.05.

Flow Characteristics

Berry Brook daily flows were analyzed in conjunction with two nearby USGS gaged reference reaches. The Isinglass and Oyster River were used as reference watersheds to understand the differences in climatic shifts between the two time periods. All flow values were normalized by watershed area for comparison. A two part analysis was used to assess the changes in Berry Brook flow characteristics by time period. The first analysis tested the null hypothesis that daily flows for the Isinglass and Oyster River were not different by pre$_{UD}$ and post$_{UD}$ time periods. The second analysis tested the null hypothesis that the daily flow difference (delta) between Berry Brook and a reference gage was not different by time period. This relationship was tested for average, maximum, and minimum daily flows for both references gages and Berry Brook monitoring locations. Independent Wilcoxon/Kruskal-Wallis (Rank Sums) non-parametric tests were used to determine statistical differences in distributions.

In addition to the daily flow analysis, Berry Brook storm event hydrograph parameters were compared between time periods. Direct runoff hydrographs were calculated using a constant slope baseflow separation. The runoff hydrographs were then converted into unit hydrographs for comparability. Direct runoff unit hydrographs from both upper and lower watershed locations were compared by time periods of pre_{UD} and $post_{UD}$. Parameters statistically analyzed are shown in Table 2-2.

Table 2-2: Analytical Parameters-Direct Runoff Hydrograph

mean (cfs/in)
median (cfs/in)
standard deviation
skew
kurtosis
Volume (ft^3)

Impervious and Effective Impervious Cover

Direct runoff depths (in) were computed from the direct runoff volumes divided by the watershed area. Runoff volumes were computed using a constant slope baseflow separation. The relationship between direct runoff (in) and rainfall depth (in) was plotted and a linear regression was fit to the data. The slope of the regression for urban watersheds is considered to be the fractional effective impervious area and the x-intercept as the initial abstraction or initial losses (Boyd et al. 1994). The linear regressions were compared at the upper and lower watersheds between pre_{UD} and $post_{UD}$ time periods. To compare regression slopes and initial abstractions, 95% confidence intervals were plotted to assess significance. In addition to field measured data various empirical methods for determining EIC_{pre} and EIC_{post} were also plotted to serve as a comparison. All methods for determining IC and EIC are described and shown in Table 2-3: Impervious Cover and Effective Impervious Cover Methods. Empirical and mapped values were plotted as a linear regression with an assumed x-intercept of 0.1 rainfall inches based on Sutherlands work and typical values of initial abstractions. The slope of the regression was based on the calculated EIC or IC value. IC_{pre} was reflective of the values from the GIS results provided by the UNH Complex Research Center (Appendix A - Berry Brook Watershed). IC_{post} was the difference between mapped and treated IC (Table 2-3). Impervious cover runoff was considered treated if the runoff was directed to an appropriately sized LID such as a bioretention, tree filter, or porous pavement sized as per a stormwater manual (UNHSC 2012a). EIC_{pre} was computed using two methods, Sutherland's empirical equation for average basins and an optimized USGS equation (Table 2-3). Sutherland developed several equations EIC equations that varied by watershed characteristics. For example, average basins were considered urban areas with mostly storm sewered drainage, curbs and gutters, no dry wells or infiltration, and residential rooftops that are not directly connected (Sutherland 1995). Two empirical methods were compared in approximating EIC_{post} values. The first method was an application of Sutherland's equation to the IC_{post} values and the second was an EPA BMP disconnection method (Table 2-3). The EPA method describes IC disconnection as a function of volume reduction that can be achieved by various BMP practices (EPA 2011). The BMP multiplier values are based on system effectiveness to reduce volume. For example, removal of pavement and restoration of infiltration capacity (100% runoff reduction) would receive a BMP multiplier of 0 and a BMP with no runoff reduction would receive a multiplier of 1. All other BMP practices fall between a multiplier range of 0-1 (EPA 2011).

Table 2-3: Impervious Cover and Effective Impervious Cover Methods

Method	Equation	Approach	Reference
Pre-LID			
IC_{pre}/Mapped IC	GIS delineation	Typical:30-meter Landsat 5 Thematic Mapper (TM) satellite data Berry Brook: polygon discretization using 1 foot aerial image	(Justice et al. 2006)
$EIC_{pre\text{-}Sutherland}$	$EIC\% = 0.1 * (IC\%)1.5$ Average: Mostly storm sewered with curb & gutter, no dry wells or infiltration, residential rooftops are not directly connected.	Runoff vs. rainfall regression based on watershed criteria.	(Sutherland 1995)
$EIC_{pre\text{-}USGS}$	$EIC\% = 3.6 + 0.43 * (IC\%)$	Optimized equation based on modeled and gaged data	(Laenen 1983)
EIC_{pre}	Slope of direct runoff depth vs. rainfall linear regression	Developed regression based on measured runoff volumes and rainfall depths	(Boyd et al. 1994)
Post-LID			
IC_{post}	$IC_{post} = (IC_{pre} - treated\ IC)$	Treated IC = IC runoff that is treated by an appropriately sized LID	(UNHSC 2012a)
$IC_{post\text{-}WQV}$	$IC_{post} = IC_{pre} * \left(\frac{WQVcriteria - WQVdesign}{WQVcriteria}\right)$	Fractional IC disconnection based on WQV treated	Hlas, Roseen
$EIC_{pre\text{-}Sutherland}$	$EIC\% = 0.1 * (post - IC\%)1.5$	Re-apply Sutheralnds equation to post-IC as calculated above	(Sutherland 1995)
$EIC_{post\text{-}EPA}$	$EIC = Pre - EIC - IC * (1 - BMP\ Multiplier)$	reduction is based on IC treated multiplied by BMP factor as a function of volume reduction for the particular system	(EPA 2011)
EIC_{post}	Slope of direct runoff depth vs. rainfall linear regression	Develop regression based on measured runoff volumes and rainfall depths	(Boyd et al. 1994)

Water Quality

Iron (Fe) and bacteria (E.coli) where reported based on wet and dry weather sampling throughout the monitoring period (Appendix C - Water Quality). This data was examined qualitatively and adds to the background data for Berry Brook. Storm event water quality parameters shown in Table 2-4 were statistically analyzed using an independent Wilcoxon Exact Rank Sums test for a comparison between pre_{LID} vs. $post_{LID}$ time periods. In addition to these tests, it was hypothesized that during the pre_{LID} period, event mean concentrations of water quality parameters were greater at the upper watershed vs. lower watershed. A matched pair exact sign test was used to statistically test this relationship.

Table 2-4: Analytical Parameters-Water Quality

total suspended solids –TSS
total nitrogen-TN
total kjeldahl nitrogen-TKN
nitrate-NO^3
total phosphorus-TP
Ortho-phosphate-PO_4
Zinc-Zn

2.3.5 Modeling Methods

The Berry Brook Watershed was modeled using PCSWMM 2012 software by Computational Hydraulics International (CHI) (Figure 2-3). Three PCSWMM watershed models were built to examine the long-term response of restoration efforts. A Pre_{model} represented the watershed prior to improvements. Two other models were constructed to simulate the watershed post-construction with LID and stream restoration improvements. One method simulated LID implementation (LID_{model}) and the other a reduction in EIC (EIC_{model}) which consequently increased the fractional pervious cover. Reduced EIC subcatchment values for the EIC_{model} were determined by a combination of field measured values and Sutherland's method. The models were constructed with available GIS information for area and subwatershed delineations and field survey elevation data completed by University of New Hampshire Stormwater Center (UNHSC). Subcatchment, junction, conduit, and storage input parameters and calibration details are provided in Appendix E – Model Calibration. Dynamic Wave routing and Green-Ampt infiltration computational modeling methods were used for simulation. Dynamic wave routing was selected to account for the watershed culvert inconsistencies and possible backwater effects at various sections of the stream. Manning's equation was used to related flow to depth and friction slope. Subcatchments were imported from hydrologically delineated area shape files. Directly connected impervious cover areas (DCIA or EIC) were computed based on measured values and Sutherland's relationship. The pervious cover infiltration parameters were aerially weighted by hydrologic soil group delineations from the Natural Resources Conservation Service (NRCS) soil data bank. From this delineation hydrological soil groups were assigned typical infiltration values (Akan and Houghtalen 2003). Junctions and conduits were defined by the City of Dover storm sewer information and UNHSC field survey and verification.

The water quality component was built into the models by assumptions of the simple method that calculates pollutant loading based on assigned land uses and event mean wash-off concentrations. Water quality modeling focused on TSS, TN and TP. Prior to calibration each land use was assigned a typical event mean concentration (UNHSC 2012a). In order to simulate pollutant treatment in the LID_{model} typical LID removal efficiencies were used based on referenced values from the "UNHSC 2012 Biennial Report" and "Water Quality and Quantity Performance Review of Bioretention Design Criteria and Operating Conditions". The objective of the model was to a) simulate long term continuous flow data and compare flow duration curves, volumes, and peak between pre_{LID} and $post_{LID}$ watershed improvement periods and b) simulate and observe a design storm event with respect to peak and volume. Similarly, the water quality modeling objectives were to run a continuous simulation and a design event to observe changes in pollutant loads between the respective model scenarios.

The PCSWMM long-term model simulation used a 20 year hourly precipitation data set from the local UNH weather station (1/1/1990-12/31/2009). This rainfall record was selected to provide historical local data with limited gaps. The SCS 24h Type-II 1 inch rainfall design storm was selected to compare the three models and overlay the hydrograph response in PCSWMM.

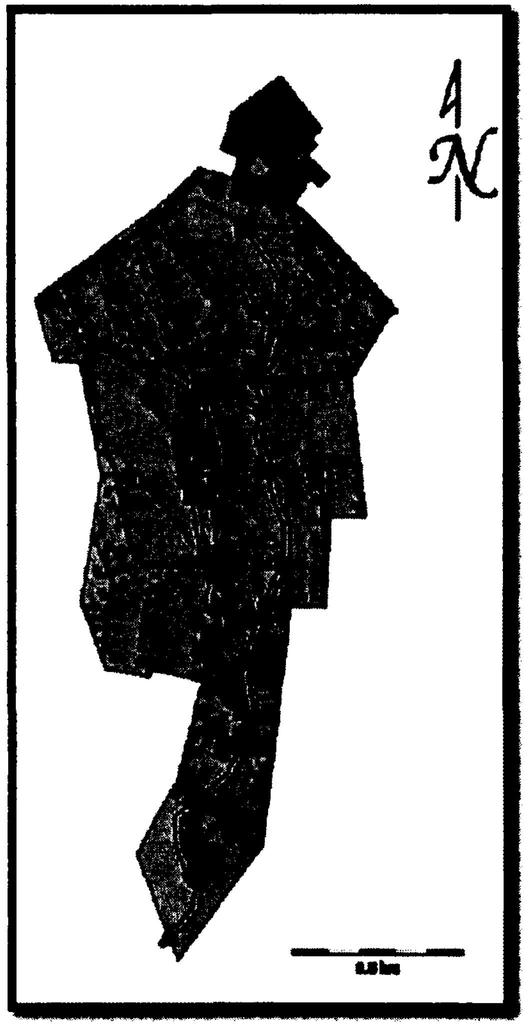


Figure 2-3: PCSWMM Berry Brook Model

2.3.6 Modeling Calibration

The Berry Brook model was calibrated against observed hydrological data at the lower watershed monitoring location. Input rainfall data for the calibration periods was obtained from the Kingman Farm NOAA weather station (station# :54794) as hourly precipitation. The weather station is located approximately 5 miles from the Berry Brook Watershed. Model parameters were calibrated based on uncertainty. A detailed table of calibrated parameters is shown Appendix E – Model Calibration. "Sensitivity-based radio tuning calibration" platform allowed for multiple parameter adjustments at once. The main calibration parameters included junction inflows, overland flow path lengths, conduit roughness and soil conductivity. The goal of the model was to maximize the r-squared and minimize the root mean square error (RMSE) of event peak flows and total runoff volumes. Calibration methods and targets were referenced from, "Measured and Simulated Runoff to the Lower Charles River, Massachusetts, October 1999-September 2000 (Zarriello and Barlow 2002). Calibration results are reported in Appendix E – Model Calibration Results. Post-LID model calibration was focused on baseflows and groundwater metrics.

The calibrated values were checked using PCSWMM's Engineering Audit Tool that compared all model parameter values versus common ranges. All values fell within common ranges.

2.4 Results and Discussion

2.4.1 Hydrology

Flow Characteristics

Examining daily flow characteristics of two reference reaches indicates that there is a difference between pre$_{LID}$ and post$_{LID}$. The Isinglass and Oyster River both have a statistically greater average, maximum, and minimum area weighed flow during the post-LID period (Table 2-5).

Area weighted flows for the reference reaches were compared with the Berry Brook flows for the two time periods. Figure 2-4 presents average daily area weighted flow of Berry Brook-lower watershed and the Isinglass for the period of monitoring. This time series shows that during pre$_{LID}$ the Isinglass River plots well below Berry Brook. This difference declines as time progresses and as watershed restoration efforts are implemented. During post$_{LID}$ the time series overlay each other (Figure 2-4). This relationship was statistically tested by examining the difference (delta) in daily average, maximum, and minimum area weighted flows between Berry Brook and the reference gages and found that the difference was statistically greater during pre$_{LID}$ (Table 2-5). These results indicate that there is a significant change in Berry Brook flows despite the effect of climatic variation. Post$_{LID}$ differences between Berry Brook and the reference reaches were closer to zero. This observation was made despite increased daily flow characteristics for the reference reaches during post$_{LID}$. This indicates that Berry Brook post$_{LID}$ daily hydrology is more closely representative of an undisturbed watershed.

An examination of the flow duration curves shown in Figure 2-5 indicates that during Pre_{UD} the Isinglass and Berry Brook-lower watershed have significantly different area weighed flows. This difference or delta substantially increases above a probability of non-exceedance of 0.90 (Figure 2-5). This implies that during periods of rain or increased flows the Isinglass and Berry average daily flow are very dissimilar in magnitude. This may be attributed to the differences in watershed urbanization or impervious cover. The flow duration curves also indicate that during $post_{UD}$ the average daily flow for the Isinglass River was greater. The opposite is true for the Berry Brook flows, during $post_{UD}$ the curve plots to the left indicating a decrease in daily flows. During $post_{UD}$ the Isinglass and Berry Brook area weighed flows intersect at both low flows and high flows (Pn: ~0.22, 0.93). These results show that Berry Brook dry and wet weather flows are more closely related to an undisturbed watershed during $Post_{UD}$. This would be expected with the reduction of effective impervious cover and watershed improvement efforts.

Table 2-5: Non-Parametric Independent Wilcoxon Statistical Analysis of Daily Flow per Watershed Area by Time Period

	Pre-LID		Post-LID		
Variable	**n**	**Mean Score**	**n**	**Mean Score**	**p-value**
Isinglass Avg	126	73.6	74	146.3	<0.0001
Isinglass Max	126	74.3	74	145.2	<0.0001
Isinglass Min	126	72.9	74	147.5	<0.0001
Oyster Avg Daily	126	84.2	74	128.3	<0.0001
Oyster Max Daily	126	85.1	74	126.7	<0.0001
Oyster Min Daily	126	83.0	74	130.3	<0.0001
ΔAvg BB-Lower - Oyster	86	112.9	74	42.8	<0.0001
ΔMax BB-Lower - Oyster	86	109.1	74	47.3	<0.0001
ΔMin BB-Lower - Oyster	86	117.5	74	37.5	<0.0001
ΔAvg BB-Lower - Isinglass	86	112.0	74	44.0	<0.0001
ΔMax BB-Lower - Isinglass	86	108.1	74	48.5	<0.0001
ΔMin BB-Lower - Isinglass	86	116.4	74	38.8	<0.0001
ΔAvg BB-Upper - Oyster	123	124.6	74	56.5	<0.0001
ΔMax BB-Upper - Oyster	123	121.4	74	61.7	<0.0001
ΔMin BB-Upper - Oyster	123	127.2	74	52.1	<0.0001
ΔAvg BB-Upper - Isinglass	123	124.9	74	56.0	<0.0001
ΔMax BB-Upper - Isinglass	123	121.9	74	60.9	<0.0001
ΔMin BB-Upper - Isinglass	123	127.2	74	52.1	<0.0001

*Upper- Roosevelt (DA=46.4 acres), Lower-Station (DA =184.8 acres)

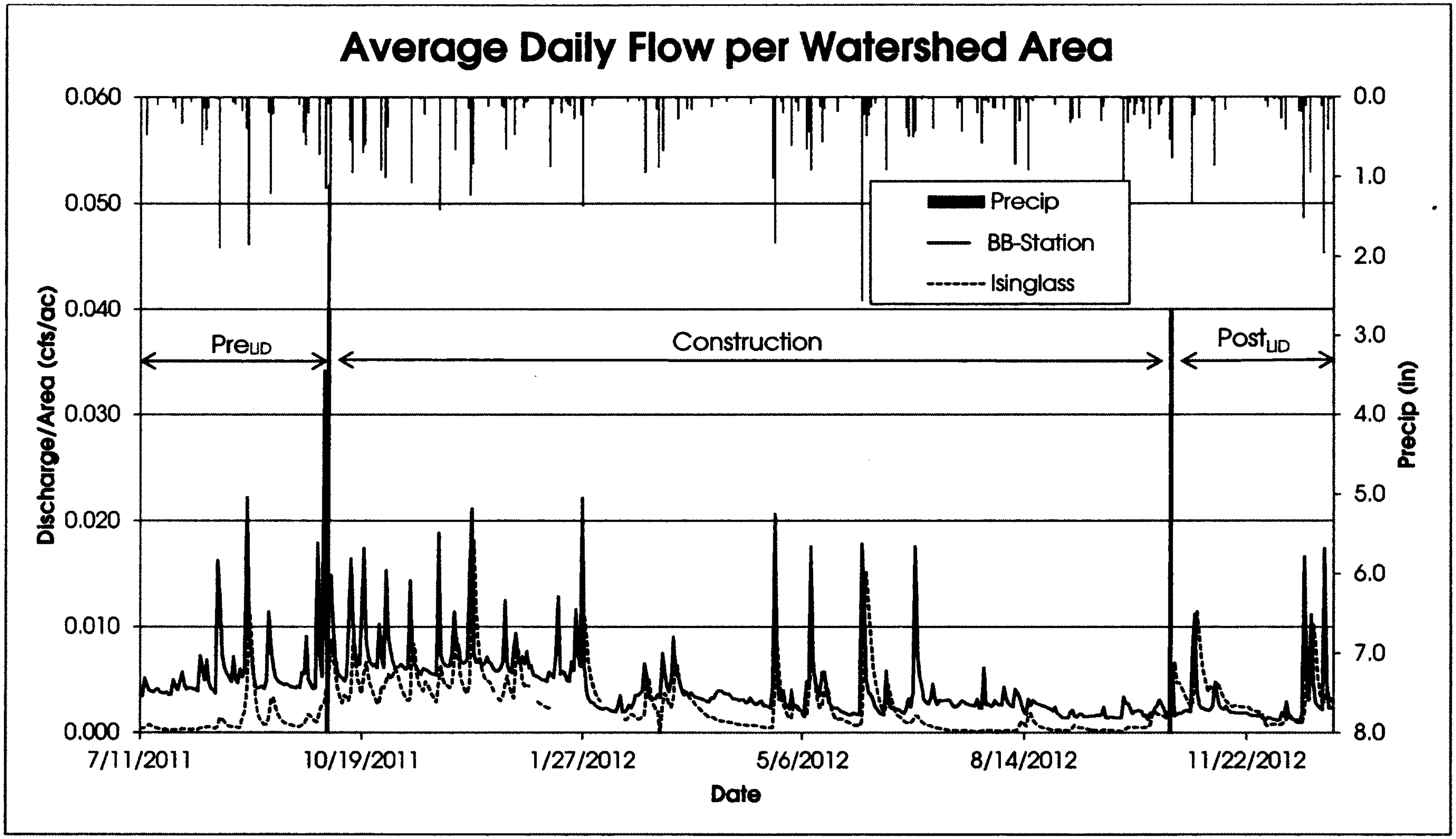


Figure 2-4: Average Daily Area Weighted Flow Comparison of Berry Brook-Lower Watershed (Station, DA = 184.8 acres) and Isinglass River (DA = 73.6 sq. miles)

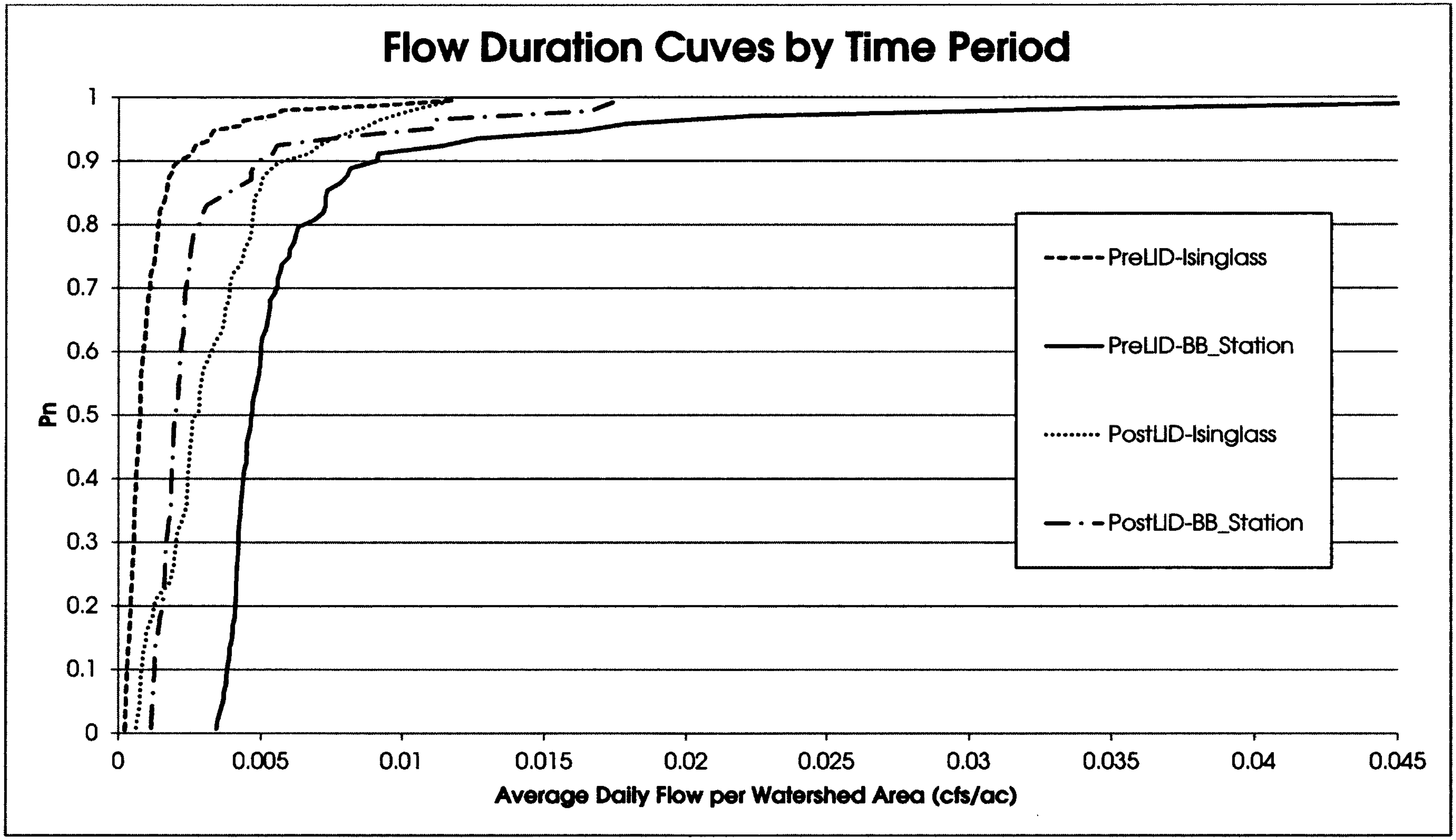


Figure 2-5: Flow Duration Curve for Average Daily Area Weighted Flow Comparison of Berry Brook-Lower Watershed (Station, DA = 184.8 acres) and Isinglass River (DA = 73.6 sq. miles) for Pre$_{LID}$ (86days) and Post$_{LID}$ (74days)

Upper Watershed - Roosevelt

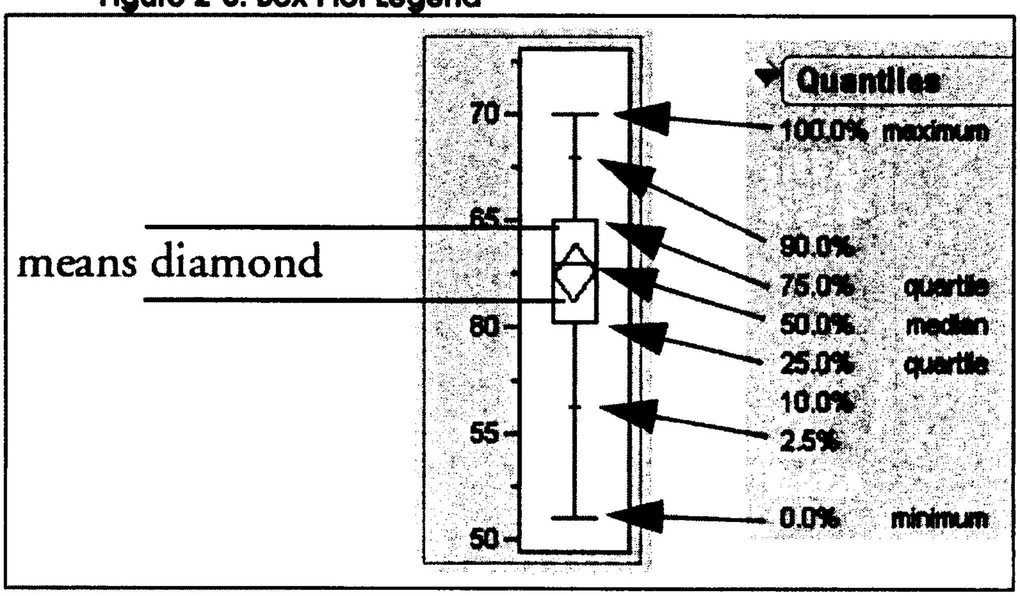
The direct runoff unit hydrographs at both Berry Brook monitoring locations were treated as probability distributions and thereby tested between pre_{LID} and $post_{LID}$ in terms of mean, median, standard deviation, skew, kurtosis, and peak as well runoff hydrograph volumes (Table 2-6). In the upper watershed an increased standard deviation and reduction in runoff volume showed an improvement in terms of hydrograph parameters (Figure 2-7). Storm event runoff volumes seemed to decrease during $post_{LID}$ (p-value: 0.107) as would be expected with LID implementation (Table 2-6, Figure 2-7). Mean, median and peak flows (p-values: 0.065, 0.084, 0.133) seem to be greater during the $post_{LID}$ time period (Table 2-6, Figure 2-7). These results could be representative of the changes in routing and stream restoration activities that occurred in the various subwatersheds above Roosevelt Street. Pre_{LID} conditions in the upper watershed were represented by a drainage network with broken pipes and sub-catchment swales that terminated prior to any outlet. Kurtosis and skew distributions between time periods were not significantly different.

Table 2-6: Non-Parametric Independent Wilcoxon Statistical Analysis of Direct Runoff Hydrograph Parameters by Time Period

		Pre-LID		Post-LID		One Sided
Location	**Variable**	**n**	**Mean Score**	**n**	**Mean Score**	**p-value**
Upper	Mean (cfs/in)	15	10.40	8	15.00	0.065
Upper	Median (cfs/in)	15	10.53	8	14.75	0.084
Upper	Std Dev	15	10.93	8	14.00	0.162
Upper	Skew	15	12.93	8	10.25	0.200
Upper	Kurtosis	15	12.60	8	10.88	0.296
Upper	Peak (cfs)	15	10.80	8	14.25	0.133
Upper	Volume (ft^3)	15	13.33	8	9.50	0.107
Lower	Mean (cfs/in)	17	13.47	10	14.90	0.338
Lower	Median (cfs/in)	17	14.29	10	13.50	0.412
Lower	Std Dev	17	14.52	10	13.10	0.338
Lower	Skew	17	15.12	10	12.10	0.180
Lower	Kurtosis	17	14.94	10	12.40	0.222
Lower	Peak (cfs/in)	17	14.71	10	12.80	0.285
Lower	Volume (ft^3)	17	15.47	10	11.50	0.112

*Upper- Roosevelt (DA=46.4 acres), Lower-Station (DA =184.8 acres)

Figure 2-6: Box Plot Legend



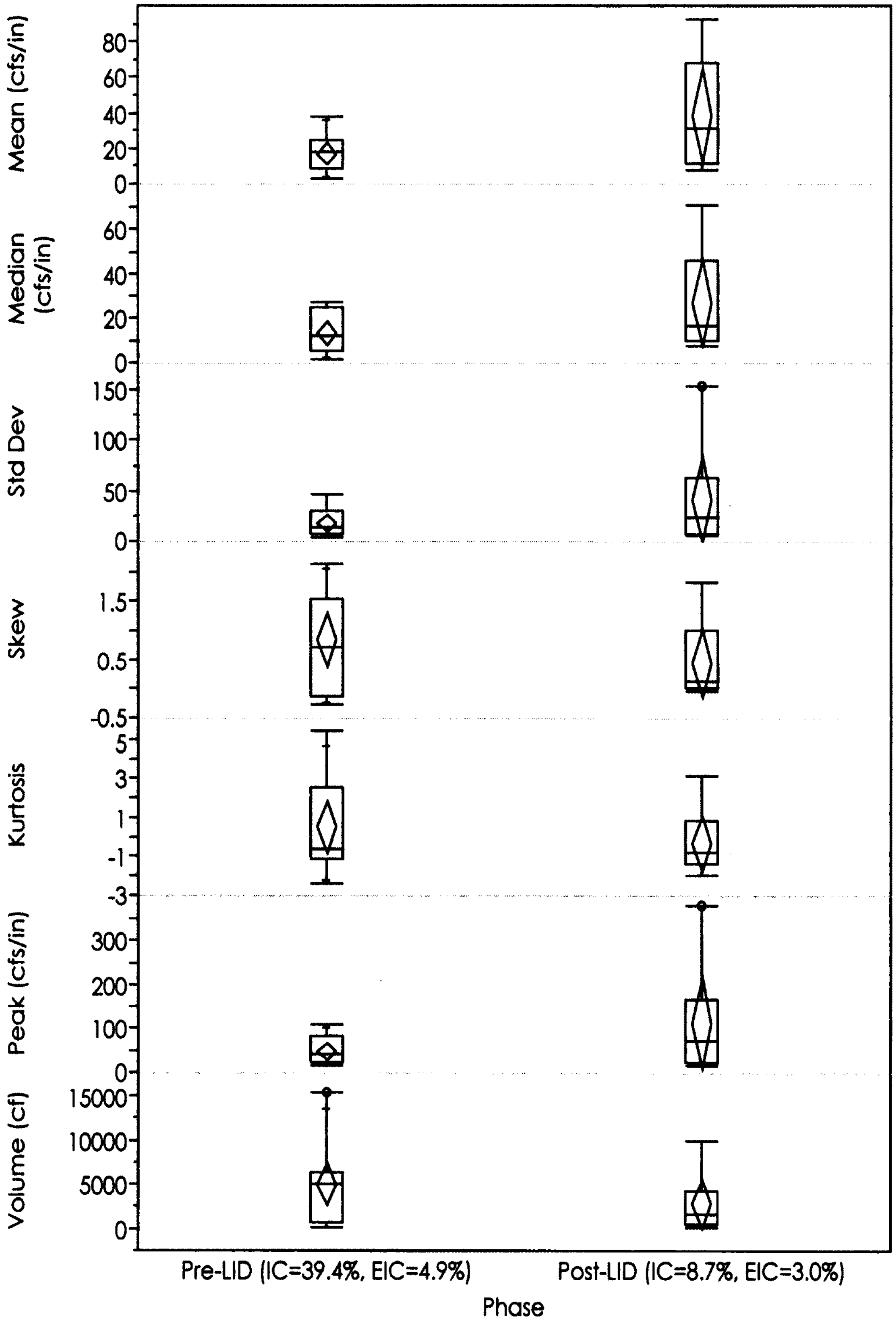


Figure 2-7: Direct Runoff Unit Hydrograph Parameters at Upper Watershed (Roosevelt, DA = 46.4 acres) for 19 Storms Pre_{LID} (06/11-10/11) and 9 Storms $Post_{LID}$ (10/12-12/12)

Lower Watershed-Station

In the lower watershed a decrease in the $post_{LID}$ storm event runoff volumes was the most statistically significant result (Table 2-6, Figure 2-8). A comparison of median runoff volumes between pre_{LID} and $post_{LID}$ shows a reduction of 46%. Furthermore, it appears that the kurtosis distribution was reduced during $post_{LID}$ (Figure 2-8). A reduced kurtosis indicates less peakedness in the hydrograph which could be a positive indication of EIC disconnection. A decrease in skew is also evident in the $post_{LID}$ distribution (Figure 2-8) Aside from volume reduction and a change in kurtosis and skew the lower watershed seemed to experience less statistically significant changes in hydrograph parameters as compared to the upper watershed (Table 2-6). This may be an indication of differences between measuring change at a subwatershed scale as opposed to watershed scale. It is suspected that changes would be more dramatic on a smaller scale. Examination of Figure 2-8 indicates that there exists considerable overlap in mean, median and standard deviation with respect to time period.

Overall, the comparison of the direct runoff hydrographs at both Berry Brook monitoring locations provided evidence for volume reductions in the $post_{LID}$ phase despite an observed increased daily average, maximum and minimum flow for the reference reaches. Volume reduction can be attributed to evapotranspiration, infiltration, and runoff lags caused by routing and outlet control of the implemented LID systems. There is also an indication of increased mean, median, and peak flow in the upper watershed which may be attributed to the stream restoration and other watershed improvements. Storm event peaks and volumes are discussed later in a modeled comparison between pre_{UD} and $post_{UD}$ where a long term simulation improved the sample size and statistical significance.

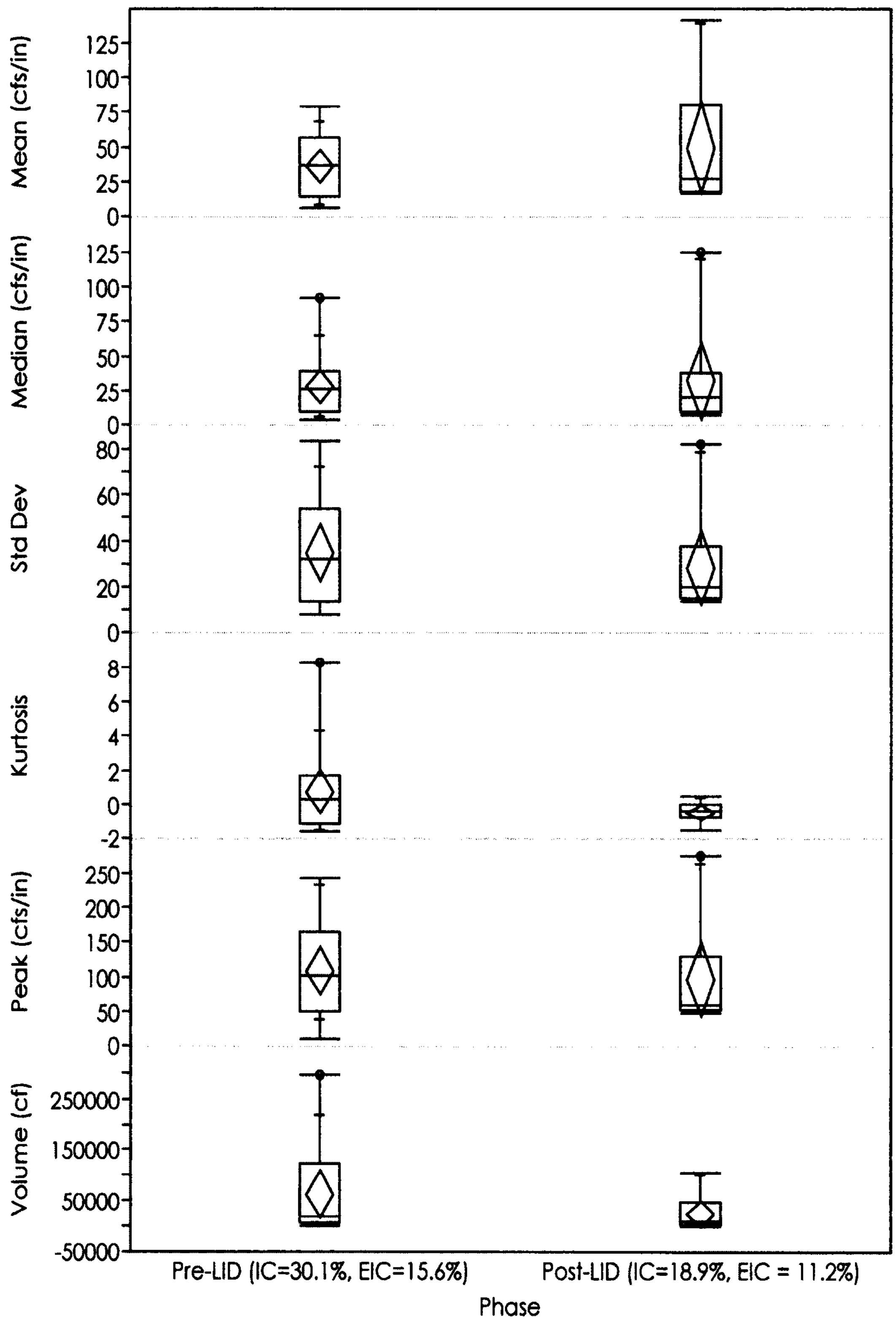


Figure 2-8: Direct Runoff Unit Hydrograph Parameters at Lower Watershed (Station, DA = 184.8 acres) for 17 Storms Pre$_{LID}$ (07/11-10/11) and 11 Storms Post$_{LID}$ (10/12-12/12)

Impervious and Effective Impervious Cover

Direct runoff (in) versus rainfall (in) was plotted to examine the relationship between a) pre_{LID} and $post_{LID}$ time periods, b) measured IC and EIC and c) empirical methods of determining EIC (Figure 2-7, Figure 2-9). Consequently, the slope of the runoff vs. rainfall linear regression serves as the EIC and the x-intercept as the initial abstraction for urban watersheds (Boyd et al. 1994).

Lower Watershed-Station

The lower watershed monitoring location had a pre_{LID} mapped IC of 30.1% (Figure 2-9, Table 2-7). Using Sutherland's method for an urban basin with mostly storm sewered drainage, $EIC_{pre\text{-}Sutherland}$ was calculated to be 16.5%. The same value was calculated using the USGS method. EIC_{pre} was measured in the field to be 15.6% (Figure 2-9). These results confirm that both Sutherland's method and the USGS equation were appropriate for determining pre_{LID} EIC in the Berry Brook watershed.

Post construction impervious cover (IC_{post}) was calculated as the difference between pre-LID and disconnected IC by treatment of an appropriately sized LID (Table 2-3). The IC_{post} was 18.9%, $EIC_{post\text{-}Sutherland}$ 8.2%, and field measured EIC_{post} was 11.7% (Figure 2-9, Table 2-7). The EPA BMP disconnection method ($EIC_{post\text{-}EPA}$) was also evaluated against field measured values. $EIC_{post\text{-}EPA}$ was calculated to be 13.8%, which slightly over predicted the field measurement of 11.7%. $EIC_{post\text{-}Sutherland}$ values seem to under approximate while the EPA BMP disconnection method over-approximated. The EPA method does not credit the subsurface gravel wetland for volume reduction which may account for some of the discrepancy in the $post_{LID}$ values. Due to constraints for urban retrofit the subsurface gravel wetland was sized to treat a 0.27 inch water quality volume. By this method the gravel wetland should not receive 100% disconnection. Taking these factors into consideration may prompt a new assessment criterion for reduction of EIC. For example, calculating the gravel wetland IC reduction as a fraction of water quality volume treated results in a watershed $EIC_{post\text{-}WQV}$ of 10.8% which improves agreement to field measured values. The following represents a proposed method for determining IC disconnection by LID treatment as a function of water quality volume:

Equation 1: $IC_{post} = IC_{pre} * \left(\frac{WQV_{criteria} - WQV_{design}}{WQV criteria}\right)$,

Where WQV is the water quality volume in inches, $WQV_{criteria}$ represents state criteria for design of LIDs and WQV_{design} symbolizes treatment depth of the field system. Further determining EIC_{post} would be calculated by empirical equation or field measurements. Considering EIC as disconnected when routing runoff through an appropriately sized LID corresponded well for volume reduction. This suggests that if all EIC was treated with LID systems, the storm event runoff volumes could mimic those similar to pre-urban development conditions.

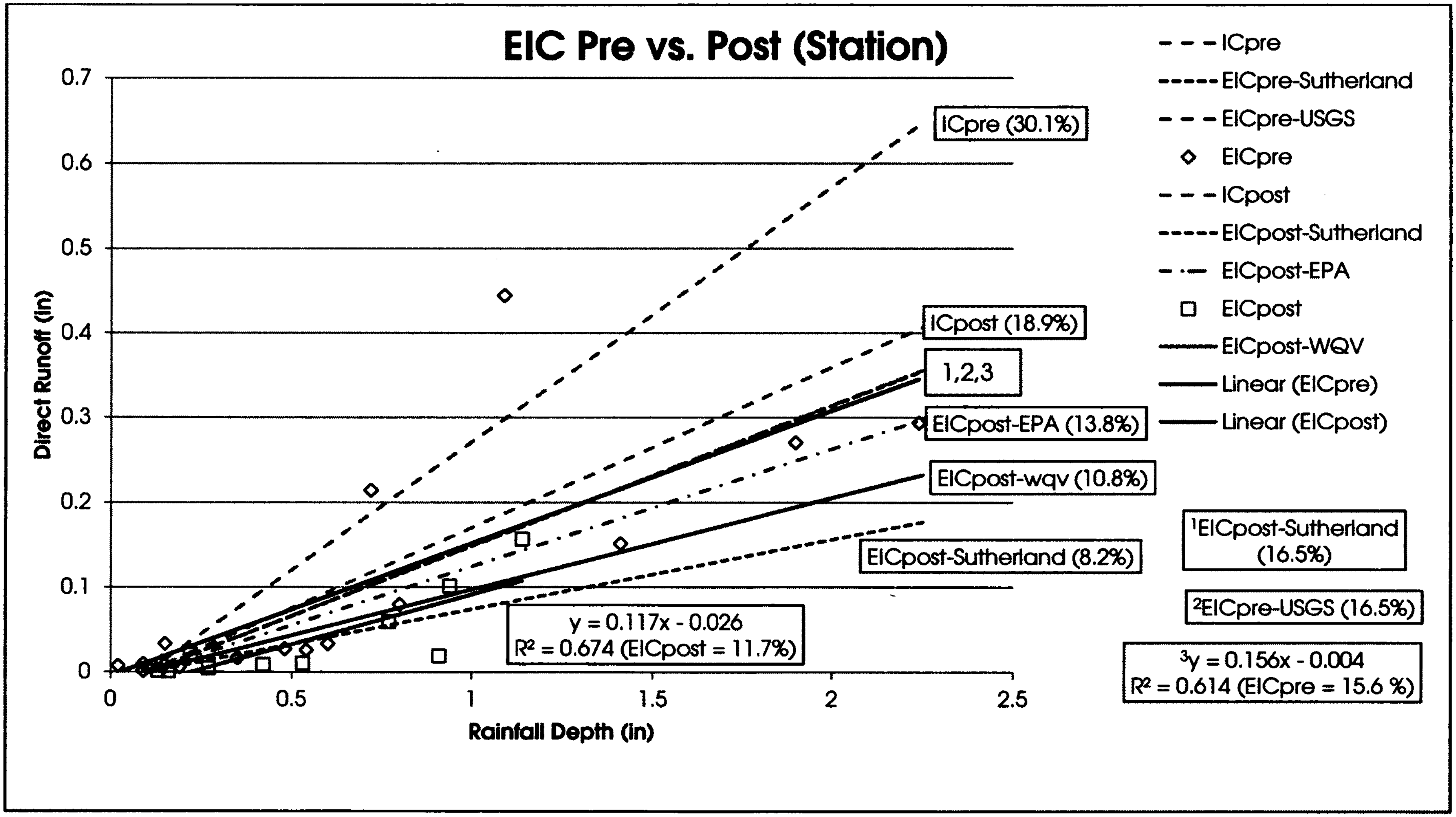


Figure 2-9: Rainfall Runoff at BB-Lower Watershed (Station, DA = 184.8 acres) by Time Period

To test whether the pre_{LID} and $post_{LID}$ linear regressions of direct runoff vs. rainfall were significantly different, confidence intervals were plotted for each regression (Appendix). The confidence intervals of the linear regressions did overlap indicating that the slopes were not statistically different between pre_{LID} and $post_{LID}$. The x-intercepts of the linear regressions increased from Ia_{pre} of 0.028 inches to Ia_{post} of 0.22 inches as would be expected from LID implementation (Figure 2-9). Overlapping confidence intervals suggest that the pre_{LID} and $post_{LID}$ initial abstractions are not significantly different (Appendix).

Upper Watershed-Roosevelt

The upper watershed IC_{pre} was 39.4%, $EIC_{pre\text{-}Sutherland}$ was found to be 24.7% and a field measured EIC_{pre} of 4.9% (Figure 2-10, Table 2-7). These values suggest that the EIC empirical methods were over predicting runoff volumes. This is likely due to the existing wetland, subwatershed connections, and routing methods along Berry Brook. Sutherland's method worked well as an empirical predictor for EIC at the watershed scale but at a subwatershed scale this relationship did not hold true.

Calculation of IC_{post} was found to be 8.7%, $EIC_{post\text{-}Sutherland}$ 2.6%, and field measured EIC_{post} was 3.0% (Figure 2-10, Table 2-7). Although pre_{LID} and $post_{LID}$ field measured values did not significantly change, the estimated value of EIC decreased due to the major LID treatment practices implemented in the upper watershed. $EIC_{post\text{-}EPA}$ was a high 20.3% (Figure 2-10, Table 2-7). As mentioned earlier this estimate may be high due to the lack of credit that the gravel wetland and some of the other systems receive for volume reduction.

The results from the upper watershed during $post_{UD}$ are highly variable and there is a lack of fit to the regression. The upper watershed underwent significant improvements and EIC reductions. There were many changes in the routing of the contributing hydrological subwatersheds that may account for the high degree of variability and difference in the relationships observed at the watershed scale.

Table 2-7: Impervious Cover and Effective Impervious Cover Results by Location

<u>Location</u>	IC_{pre} (%)	$EIC_{pre\text{-}Sutherland}$ (%)	$EIC_{pre\text{-}USGS}$ (%)	EIC_{pre} (Field Measured) (%)	EIC_{pre} Avg. (%)	IC_{post} (%)	$EIC_{post\text{-}Sutherland}$ (%)	$EIC_{post\text{-}EPA}$ (%)	EIC_{post} (Field Measured) (%)	EIC_{post} Avg. (%)
Upper	39.4	24.7	20.4	4.9	**16.7**	8.7	2.6	20.3	3.0	**8.5**
Lower	30.1	16.5	16.5	15.6	**16.2**	18.9	8.2	13.8	11.7	**11.2**

*Upper- Roosevelt (DA=46.4 acres), Lower-Station (DA =184.8 acres)

Table 2-8: Watershed %EIC by Location

<u>Location</u>	Drainage Area (acres)	Pre-EIC Field Measured (%)	Watershed EIC (%)
Upper (pre_{LID})	46.4	4.9	1.2
Upper ($post_{LID}$)	46.4	3.0	0.8
Lower (pre_{LID})	184.8	15.6	15.6
Lower ($post_{LID}$)	184.8	11.7	11.7

*Upper- Roosevelt, Lower-Station

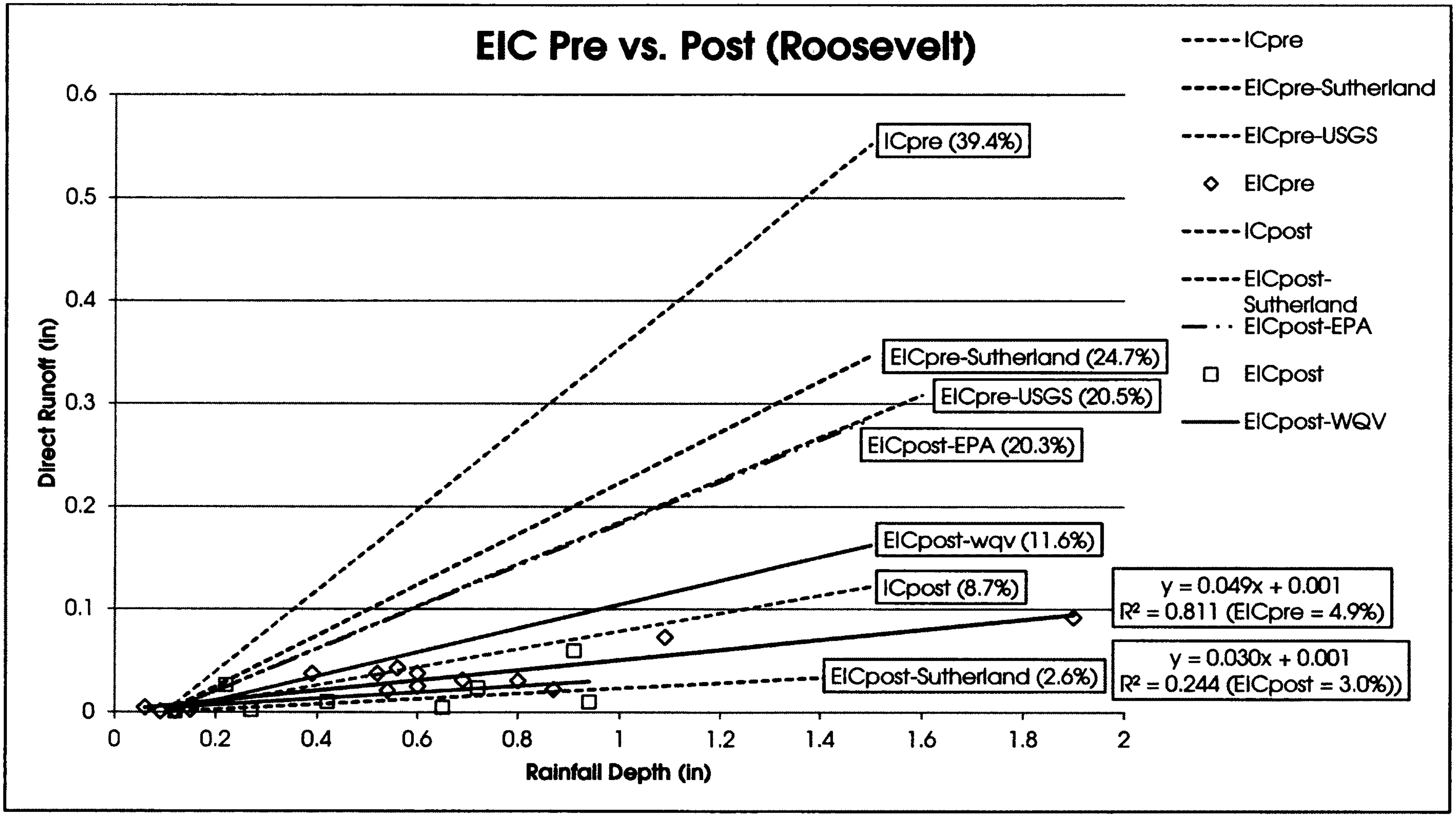


Figure 2-10: Rainfall-Runoff at BB-Upper Watershed (Roosevelt, DA = 46.4 acres) by Time Period

In addition to the EIC linear regressions, storm event runoff volume versus %EIC was plotted (Figure 2-18). The four values represent field measured watershed EIC_{pre} and EIC_{post} at the upper and lower watershed and the median runoff volume for the period of monitoring (Table 2-8). Watershed EIC is simply the subwatershed EIC divided by entire watershed area. Figure 2-18 indicates that runoff is a function of %EIC as expected. Furthermore, the reduction of %EIC also corresponds to a reduction in runoff volumes (Figure 2-18). This result prompts the question at which threshold of %EIC and runoff volumes does a watershed begin to recover from effects of urbanization? Reduction in runoff volumes can lead to improvements to storm event hydrology, water quality and baseflows that has the potential to further improve biotic integrity. This data supports the usage of %EIC as a surrogate for defining stream integrity in a generalized form.

2.4.2 Water Quality

Water quality impairments from surface runoff were one of the reasons behind the Berry Brook Watershed Renewal Project. Water quality evaluation was largely focused on storm event pollutant concentrations between pre_{UD} and $post_{UD}$ time periods. In addition to the storm event monitoring, limited baseflow water quality samples were analyzed for bacteria and other parameters.

During the period of monitoring storm events E.coli values at the lower watershed an average of 1036 cfu/ml (Appendix C - Water Quality). Baseflow E.coli values ranged between 60-310 cfu/ml (Cocheco River Watershed Coalition, Appendix C - Water Quality). During our study pH and dissolved oxygen baseflow values were not outside of typical ranges for natural waters at the lower watershed monitoring location. Baseflow turbidity typically ranged from 10-40 NTUs throughout the stream. Iron bacteria may be the primary source behind the relatively high turbidity baseflow values. Dry weather grab samples taken April 16, 2012 showed iron concentrations ranging from 0.76-11 mg/l at various locations throughout the watershed (Appendix C - Water Quality). Baseflow water quality indicates that there were continuing issues with iron and bacteria prior to $post_{UD}$ monitoring.

Upper Watershed – Roosevelt

a. Event Mean Concentrations-Upper Watershed

In the upper watershed several of the water quality parameter distributions demonstrated high variability making it difficult to statistically distinguish changes or improvements during $post_{UD}$ (Table 2-11). Storm event median concentrations of TSS, Zn, NO^3, TKN, TN, TP, and Ortho-P were statistically analyzed at the upper watershed monitoring location by time period (Table 2-9). TSS and TP indicate signs of reduction during $post_{LID}$ (p-value: 0.155, 0.097). An efficiency ratio which is median percent change by time period for TSS and TP shows a reduction of 71.8 and 78.9% (Table 2-11). Ortho-P results indicate a significant increase in median concentration during $post_{LID}$ (Table 2-9). Nitrogen concentrations did not significantly change throughout the period of monitoring. This is not surprising considering the lack of maturing time for the LID systems after the construction period. Furthermore, $post_{LID}$ monitoring was during fall-winter when plant growth and nitrogen uptake would be minimal. It should be noted that total event rainfall depth was also tested and there was not a significant difference between captured events pre_{LID} and $post_{LID}$ time periods.

Table 2-9: Non-Parametric Independent Wilcoxon Exact Statistical Analysis of Storm Event Water Quality by Time Period

		Pre-LID		Post-LID		One Sided
Location	Variable	N	Mean Score	n	Mean Score	p-value
Upper	TSS (mg/L)	10	8.90	5	6.20	0.155
Upper	Zn (mg/L)	10	8.55	5	6.90	0.264
Upper	NO3 (mg/L)	10	8.15	5	7.70	0.423
Upper	TKN (mg/L)	10	8.15	5	7.70	0.442
Upper	TN (mg/L)	10	7.90	5	8.20	0.462
Upper	TP (mg/L)	10	9.10	5	5.80	0.097
Upper	Ortho P (mg/L)	10	5.70	5	12.60	0.001
Upper	Rainfall (in)	10	7.85	5	8.30	0.445
Lower	TSS (mg/L)	11	9.45	4	4.00	0.018
Lower	Zn (mg/L)	11	9.45	4	4.00	0.026
Lower	NO3 (mg/L)	11	7.59	4	9.13	0.388
Lower	TKN (mg/L)	11	7.77	4	8.62	0.395
Lower	TN (mg/L)	11	7.64	4	9.00	0.310
Lower	TP(mg/L)	11	9.90	4	2.75	0.002
Lower	Ortho P (mg/L)	11	6.81	4	11.25	0.034
Lower	Rainfall (in)	11	8.40	4	6.88	0.300

*Upper- Roosevelt (DA=46.4 acres), Lower-Station (DA =184.8 acres)

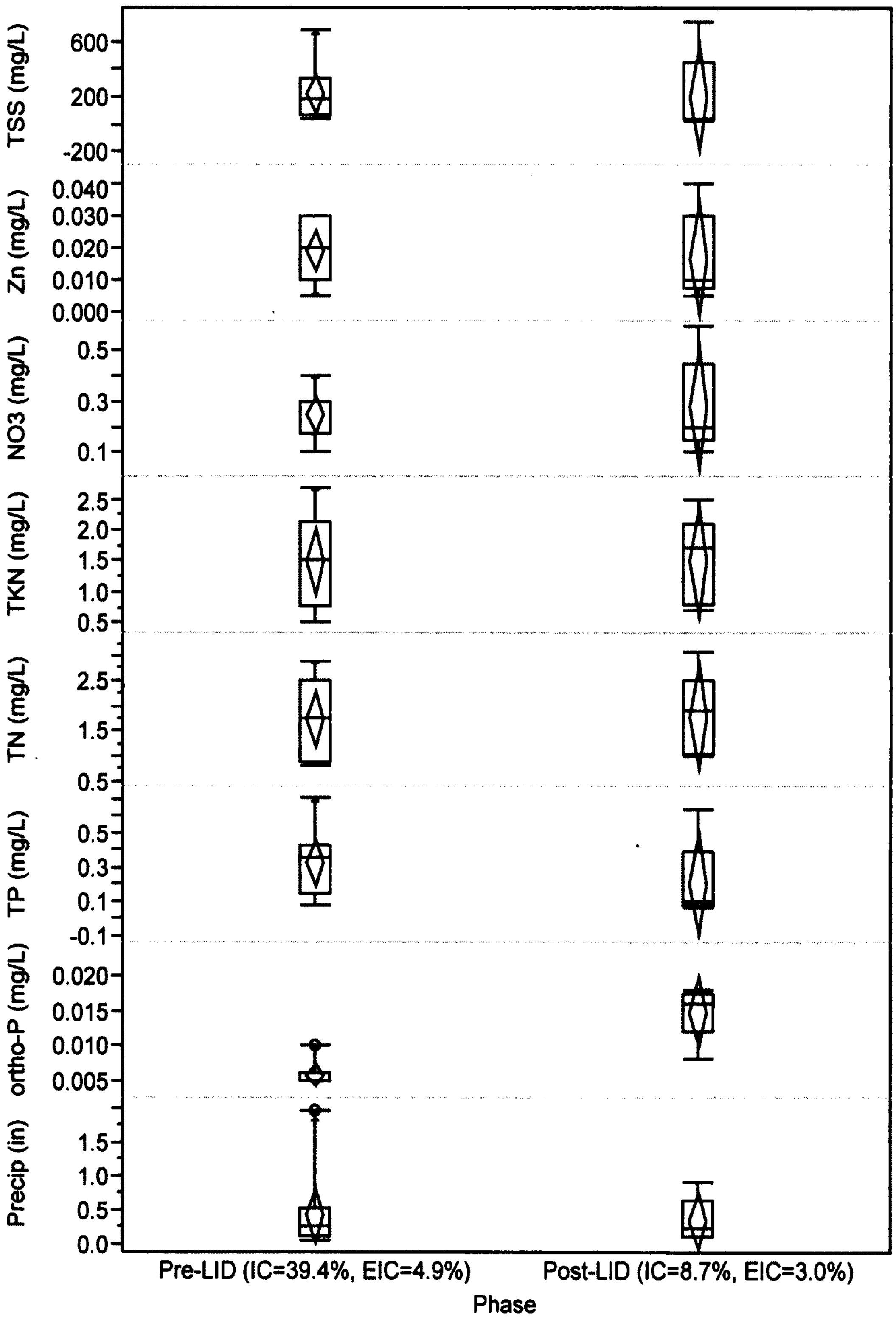


Figure 2-11: Storm Event Water Quality at Upper Watershed (Roosevelt, DA = 46.4 acres) for 10 Storms Pre_{LID} (06/11-10/11) and 5 Storms $Post_{LID}$ (10/12-12/12)

b. Pollutant Load-Upper Watershed

Storm event pollutant loads were calculated as the EMC multiplied by the direct runoff volume. Analysis of pollutant loads was similar to part a. for event mean concentrations as comparison between pre$_{LID}$ and post$_{LID}$ in the upper watershed. Based on pollutant mass TSS, Zn, TKN, TN, and TP show improvements during post$_{LID}$ (Figure 2-12). Reduction in Zn, TKN, and TN were the most significant results (p-value: 0.057) (Table 2-10). The efficiency ratio based on difference in median values further indicates improvements of 60% and greater for all tested parameters (Table 2-13) These results combine the effects of volume reduction and LID pollutant removal efficiencies. Nitrogen concentrations results showed little or no change between pre$_{LID}$ and post$_{LID}$ but improvements are observed when comparing total storm event loads primarily due to volume reduction. Similarly pollutant loads reductions in TSS and TP are shown during post$_{LID}$ but concentrations are not distinguishable (Figure 2-12). It should be noted that pollutant load per rainfall inch was also statistically tested between pre$_{LID}$ and post$_{LID}$ and showed similar results.

Table 2-10: Non-Parametric Independent Wilcoxon Exact Statistical Analysis of Storm Event Pollutant Loads by Time Period

		Pre-LID		Post-LID		One Sided
Location	**Variable**	**n**	**Mean Score**	**n**	**Mean Score**	**p-value**
Upper	TSS (Kg)	6	6.50	4	4.00	0.129
Upper	Zn (g)	6	6.83	4	3.50	0.057
Upper	NO3 (g)	6	6.17	4	4.50	0.238
Upper	TKN (g)	6	6.83	4	3.50	0.057
Upper	TN (g)	6	6.83	4	3.50	0.057
Upper	TP (g)	6	6.67	4	3.75	0.086
Upper	Ortho P (g)	6	6.33	4	4.25	0.178
Lower	TSS (Kg)	6	7.00	4	3.25	0.033
Lower	Zn (g)	6	7.33	4	2.75	0.001
Lower	NO3 (g)	6	6.83	4	3.50	0.057
Lower	TKN (g)	6	6.50	4	4.00	0.130
Lower	TN (g)	6	6.50	4	4.00	0.130
Lower	TP(g)	6	7.33	4	2.75	0.010
Lower	Ortho P (g)	6	6.50	4	4.00	0.129

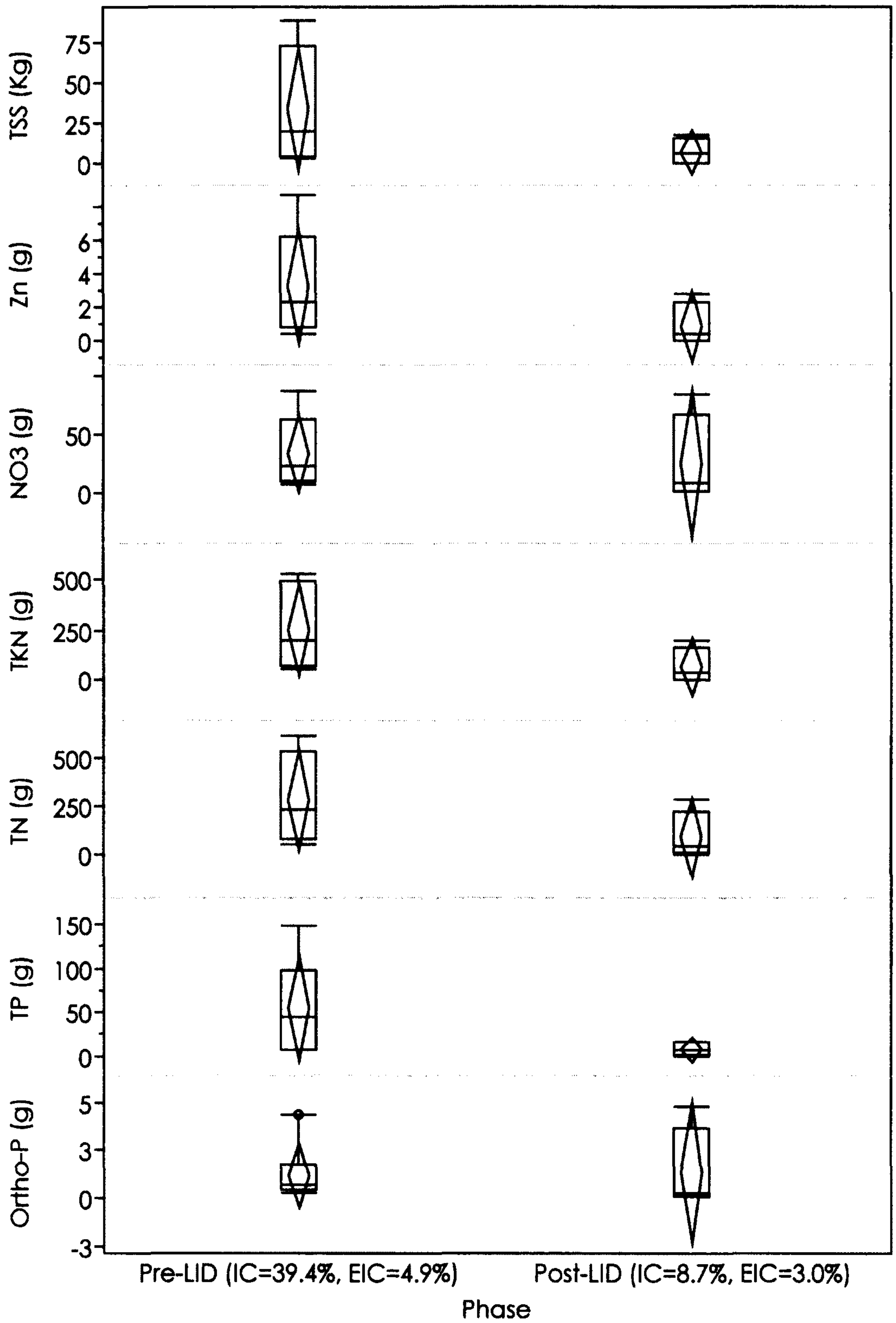


Figure 2-12: Storm Event Pollutant Loads at Upper Watershed (Roosevelt, DA = 46.4 acres) for 6 Storms Pre$_{LID}$ (06/11-10/11) and 4 Storms Post$_{LID}$ (10/12-12/12)

Lower Watershed – Station

a. Event Mean Concentrations-Lower Watershed

Examination of water quality concentration at the watershed scale showed a statistically significant reduction in TSS, Zn, and TP during $post_{LID}$ (Table 2-9). An efficiency ratio indicated reductions of TSS by 63.3%, Zn by 50.0% and TP by 77.8% (Table 2-12). Reductions of these parameters were consistent with the findings in the upper watershed. Ortho-P seemed to show a statistically significant increase during the $post_{LID}$ phase (Table 2-9). The nitrogen distributions at both monitoring locations indicated a high degree of variability and inconsistency as compared to TSS, Zn and TP (Table 2-12). Limited Nitrogen removals would be expected due to season of $post_{LID}$ monitoring and limited LID maturation.

Although this data set is relatively limited in sample size, there does seem to be concentration reductions in TSS, Zn, and TP throughout the watershed. These results would be expected as the LID systems are put online, as the systems mature, nutrient and other removals may continue to improve.

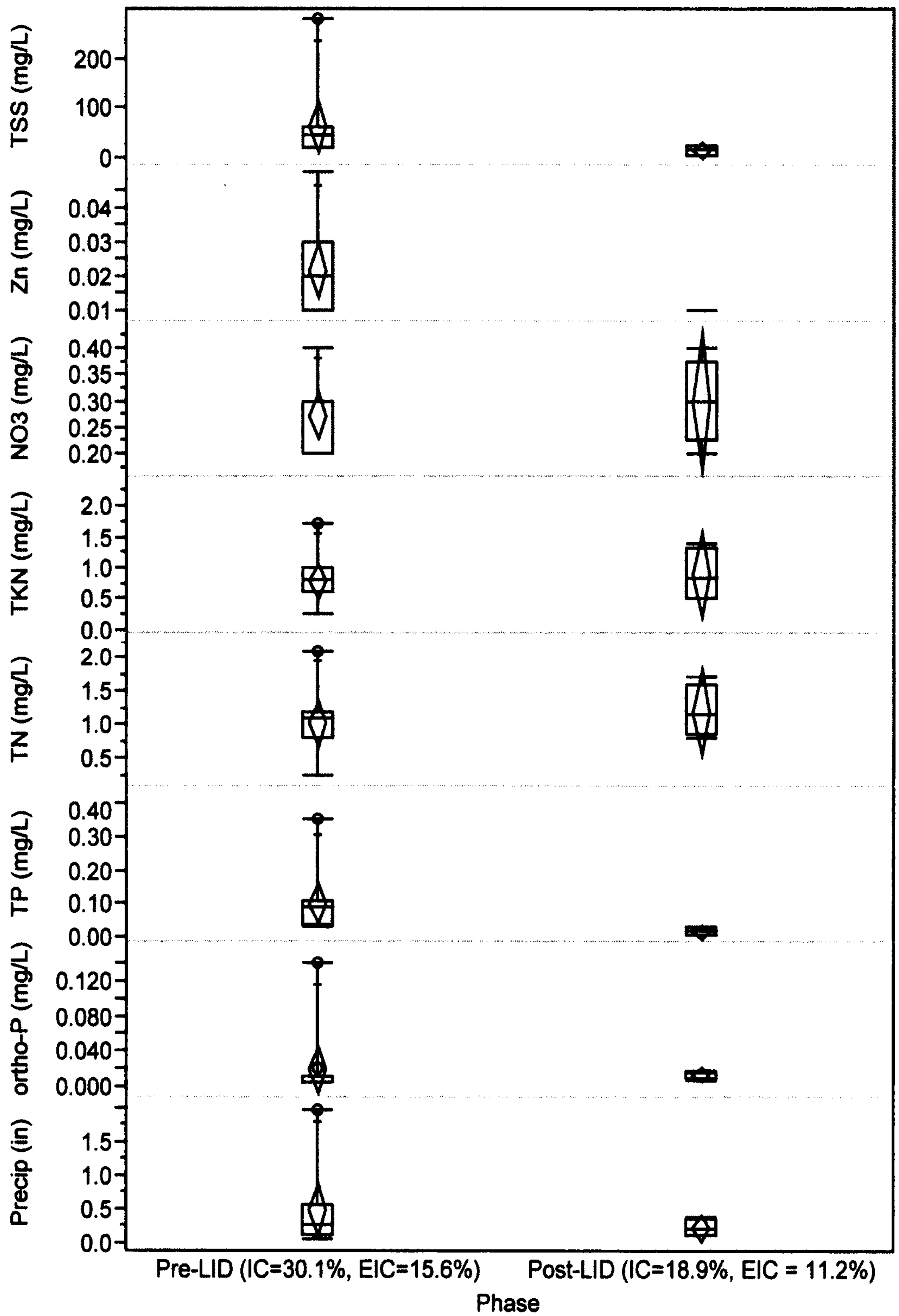


Figure 2-13: Storm Event Water Quality at Lower Watershed (Station, DA = 184.8 acres) for 11 Storms Pre$_{LID}$ (06/11-10/11) and 4 Storms Post$_{LID}$ (10/12-12/12)

A matched pair test was calculated to test the significance in event mean concentrations at upper and lower watershed during the pre_{UD} monitoring. The test revealed that TSS, TN, TKN, and TP concentrations were significantly greater in the upper watershed. These results indicate that in-stream processes are effectively removing contaminants at a greater rate than the input and contribution of IC runoff between the upper and lower watersheds. Directly upstream of the upper watershed monitoring location, three storm drains outlet into the stream, this may be another contributing reason for the high concentrations. Storm drains are not as heavily concentrated in the lower part of the watershed and dilution may be contributing factor to the observed differences.

b. Pollutant Loads-Lower Watershed

Analysis of pollutant loads at the watershed scale shows improvements for all analyzed parameters (Figure 2-14, Table 2-14). Distributions ranges during $post_{UD}$ are decreased and show low variability as compared to pre_{UD} (Figure 2-14). Efficiency ratios indicate improvements of 69% and greater for all observed parameters (Table 2-14). In general standard deviation and coefficient of variation values are high which is likely caused by the small sample size (Table 2-14). Statistical analysis results confirm these findings with significant reductions of pollutant loads for TSS, Zn, NO_3, and TP during $post_{UD}$ (Table 2-10). Results of TKN and TN also indicated improvements during $post_{UD}$ (p-value: 0.130). These results slightly differ from the EMC analysis, the difference being the change runoff volume between pre_{UD} and $post_{UD}$.

Water quality storm event median loads of TSS, TN and TP were plotted against %EIC where the four values represent the upper and lower watershed monitoring locations in pre_{UD} and $post_{UD}$ time periods (Figure 2-18). This relationship indicates that pollutant mass is related to EIC reduction. Further examination of TSS and TP seems to indicate that median mass into Berry Brook does not equal mass out (Figure 2-18). This finding was only applicable for the $post_{UD}$ matched pairs. This suggests that there are other in-stream processes and removals that cannot be solely attributed to EIC or lack of sample size during $post_{UD}$ may be skewing the relationship.

Table 2-11: Upper Watershed (Roosevelt, DA = 46.4 acres) Water Quality EMC Summary Statistics

	n		Mean		Median		Std. Dev		CV		Upper 95%		Lower 95%		ER%
Parameter	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**median**
TSS (mg/L)	10	5	224	199	190	40.0	198	311	88.2	156	366	586	82.8	-187	78.9
Zn (mg/L	10	5	0.020	0.017	0.020	0.010	0.009	0.014	45.900	82.100	0.026	0.034	0.013	-0.0003	50.0
NO^3 (mg/L)	10	5	0.25	0.28	0.30	0.20	0.10	0.19	38.90	68.70	0.32	0.52	0.18	0.04	33.3
TKN (mg/L)	10	5	1.50	1.50	1.50	1.70	0.74	0.72	49.30	48.10	2.03	2.40	0.97	0.61	-13.3
TN (mg/L)	10	5	1.75	1.80	1.75	1.90	0.79	0.84	44.90	46.80	2.31	2.85	1.19	0.75	-8.6
TP (mg/L)	10	5	0.33	0.21	0.36	0.10	0.20	0.24	60.00	119.00	0.46	0.51	0.19	-0.10	71.8
PO_4 (mg/L)	10	5	0.006	0.015	0.005	0.016	0.002	0.004	35.100	26.700	0.008	0.020	0.004	0.010	-220.0
Fe (mg/L)	0	5	-	33.4	-	15.0	-	43.1	-	129	-	86.8	-	-20.1	-
Mn (mg/L)	0	5	-	0.72	-	0.75	-	0.15	-	20.4	-	0.90	-	0.54	-

Table 2-12: Lower Watershed (Station, DA = 184.8 acres) Water Quality EMC Summary Statistics

	n		Mean		Median		Std. Dev		CV		Upper 95%		Lower 95%		ER%
Parameter	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**median**
TSS (mg/L)	11	4	65.5	15.8	45.0	16.5	73.9	10.8	53.5	68.3	113.0	32.9	13.9	-1.4	63.3
Zn (mg/L	11	4	0.022	0.010	0.020	0.010	0.012	0.082	53.500	0.000	0.030	0.010	0.014	0.010	50.0
NO^3 (mg/L)	11	4	0.27	0.30	0.30	0.30	0.06	0.08	23.70	27.20	0.32	0.43	0.23	0.18	0.0
TKN (mg/L)	11	4	0.79	0.90	0.80	0.85	0.40	0.42	50.00	47.10	1.06	1.58	0.53	0.23	-6.2
TN (mg/L)	11	4	1.03	1.20	1.10	1.15	0.51	0.39	49.20	32.60	1.37	1.82	0.69	0.58	-4.5
TP (mg/L)	11	4	0.10	0.02	0.09	0.02	0.09	0.01	88.10	70.10	0.16	0.04	0.04	0.00	77.8
PO_4 (mg/L)	11	4	0.02	0.01	0.01	0.02	0.04	0.00	211.00	34.00	0.05	0.02	-0.01	0.01	-220.0
Fe (mg/L)	0	4	-	2.64	-	1.70	-	2.40	-	90.90	-	6.46	-	-1.18	-
Mn (mg/L)	0	4	-	0.37	-	0.41	-	0.12	-	31.40	-	0.56	-	0.19	-

Table 2-13: Upper Watershed (Roosevelt, DA = 46.4 acres) Water Quality Pollutant Load Summary Statistics

	N		Mean		Median		Std. Dev		CV		Upper 95%		Lower 95%		ER%
Parameter	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	median
TSS (kg)	6	4	34	7	20	6	36	8	107	117	72	21	-4	-6	71
Zn (g)	6	4	3.4	1.0	2.3	0.5	3.2	1.3	97	137	6.8	3.0	-0.05	-1.13	79
NO3 (g)	6	4	34	25	23	8	32	40	94	158	68	89	0.3	-39	65
TKN (g)	6	4	254	69	201	38	217	89	85	128	482	211	27	-72	81
TN (g)	6	4	288	95	233	46	245	129	85	136	545	300	31	-110	80
TP (g)	6	4	56	8	44	8	56	9	101	107	115	22	-4	-6	82
PO4 (g)	6	4	1.2	1.4	0.7	0.3	1.6	2.3	126.7	170.7	2.9	5.0	-0.4	-2.3	61

Table 2-14: Lower Watershed (Station, DA = 184.8 acres) Water Quality Pollutant Load Summary Statistics

	N		Mean		Median		Std. Dev		CV		Upper 95%		Lower 95%		ER%
Parameter	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	median
TSS (kg)	6	4	85	2.9	26	1.2	117	4	139	146	208	10	-39	-4	95
Zn (g)	6	4	26.2	1.2	12.0	0.6	38.7	1.6	147.5	130.0	66.9	3.8	-14	-1.3	95
NO3 (g)	6	4	352	46	144	16	587	67	166	147	968	152	-263	-61	89
TKN (g)	6	4	973	96	347	78	1567	95	161	100	2618	247	-672	-56	77
TN (g)	6	4	1305	141	470	94	2165	159	166	113	3577	394	-966	-112	80
TP (g)	6	4	137	3.5	53	1.5	196	5	144	146	342	12	-69	-5	97
PO4 (g)	6	4	6.4	1.9	2.9	0.9	9.5	2.5	149.6	132.0	16.4	5.8	-3.6	-2.0	69

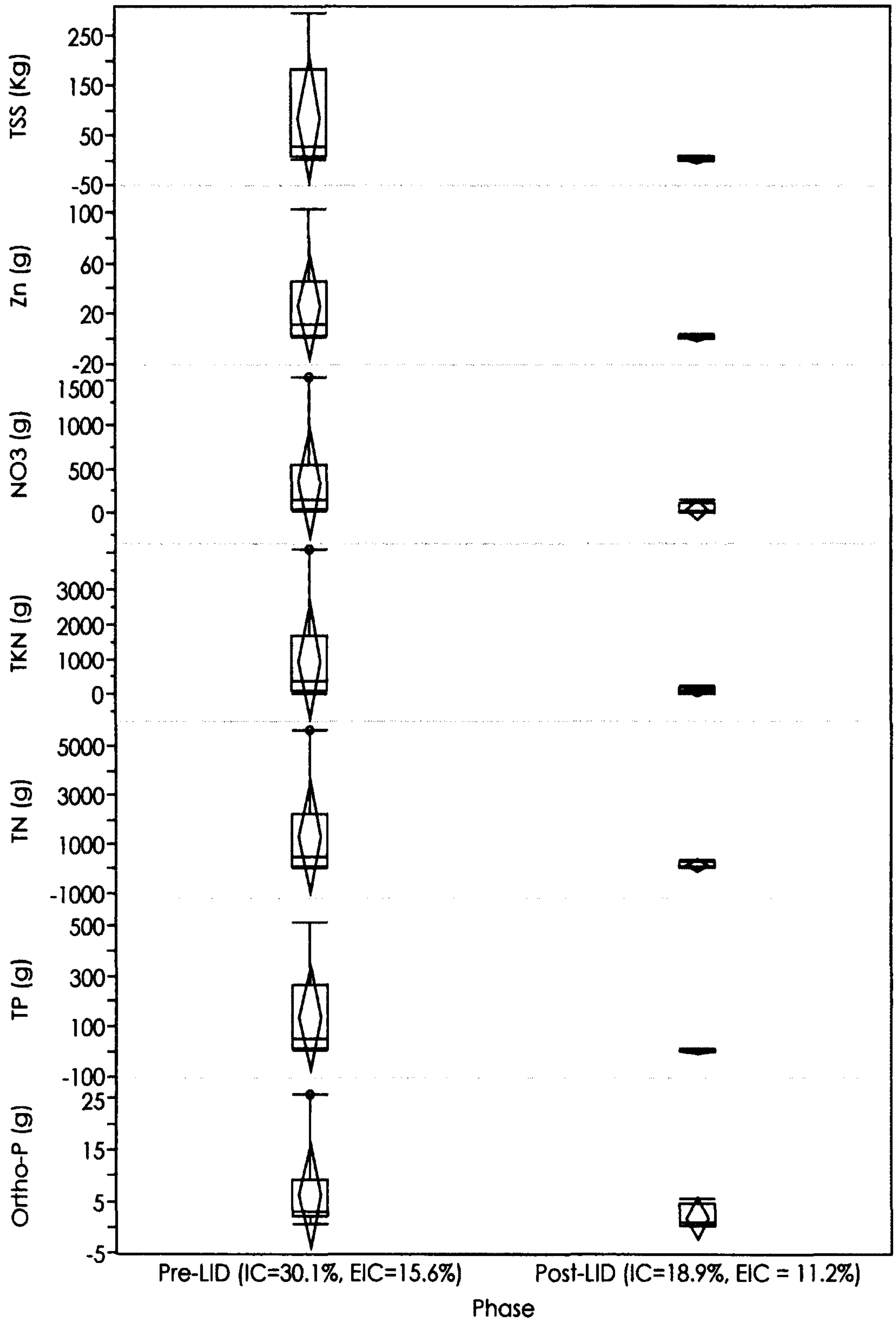


Figure 2-14: Storm Event Pollutant Loads at Lower Watershed (Station, DA = 184.8 acres) for 6 Storms Pre$_{LID}$ (06/11-10/11) and 4 Storms Post$_{LID}$ (10/12-12/12)

2.4.3 Modeling

Three separate PCSWMM watershed models were built to examine the long-term response of restoration efforts. A Pre_{model} represented the watershed prior to improvements. Two other models were constructed to simulate the watershed post-construction with LID and stream restoration improvements. One method simulated LID implementation at the system scale (LID_{model}). The other method also simulated the watershed post-construction of LID but at the watershed scale with the use of EIC (EIC_{model}). The LID_{model} is most closely representative of the post construction conditions. It should be noted that the difference in baseflows between the various models had a significant effect in the overall water quality and hydrologic results. A constant baseflow was removed in certain circumstances to better understand model comparison. Model calibration results are shown in Appendix E – Model.

Design Storm - Simulation

Examination of the simulated SCS Type-II 1inch design storm hydrograph indicates that there are changes in peak flows and total volume between the Pre_{model} and LID_{model} (Figure 2-15). The EIC_{model} seems to under approximate the peak flow as compared to the LID_{model}. The peak flow discrepancy is like due to the fact that the EIC_{model} does not generate as much runoff due to a larger fractional pervious area. The LID_{model} generates the same runoff as the Pre_{model} but peaks flows are reduced due to LID routing. In terms of volume reduction the difference between Pre_{model} and LID_{model} was about 45,000 ft^3 over the 24 hour period (Table 2-15). The EIC_{model} and LID_{model} are in good agreement in terms of volume with a difference of about 3600 ft^3 or 3%.

The SCS design storm pollutograph indicates a significant reduction in TSS, TP and TN concentrations for the LID_{model} and EIC_{model} (Figure 2-16, Table 2-15). The pollutograph for the Pre_{model} indicates a high TSS concentration at the beginning of the storm represented by the first flush. The EIC_{model} and LID_{model} show good agreement in terms of pollutant concentration peaks and overall distribution (Figure 2-16). Concentrations of TSS for the LID_{model} are slightly higher at the beginning of the storm because of the difference in baseflows (Figure 2-16). Consequently the LID_{model} has the lowest baseflows and therefore the highest concentrations in the early stages of the storm. LID performance during the modeled design storm accounts for significant load reductions, TSS by 211 lbs (32%), TN by 2.3 lbs (26%) and TP by 0.34 lbs (26%) (Table 2-15). The hydrologic results from the modeled design storm indicate that LID performance is reducing peak flow, runoff volume and pollutant load as expected with the watershed restoration efforts. Furthermore, modeling the watershed post improvements as a function of EIC reduction at the watershed scale has good agreement with respect to runoff volumes. The EIC_{model} does underestimate peaks and pollutant loads based on a comparison with the LID_{model}.

Table 2-15: Model Results-Design Storm

Model	Peak Flow cfs	Total Volume cf	TSS lbs	TN lbs	TP lbs
Pre	8.8	164,100	649	8.8	1.3
LID	8.3	119,000	438	6.5	0.96
EIC	7.6	122,600	348	4.2	0.7
Δ Pre – Post	0.5	45,100	211	2.3	0.34

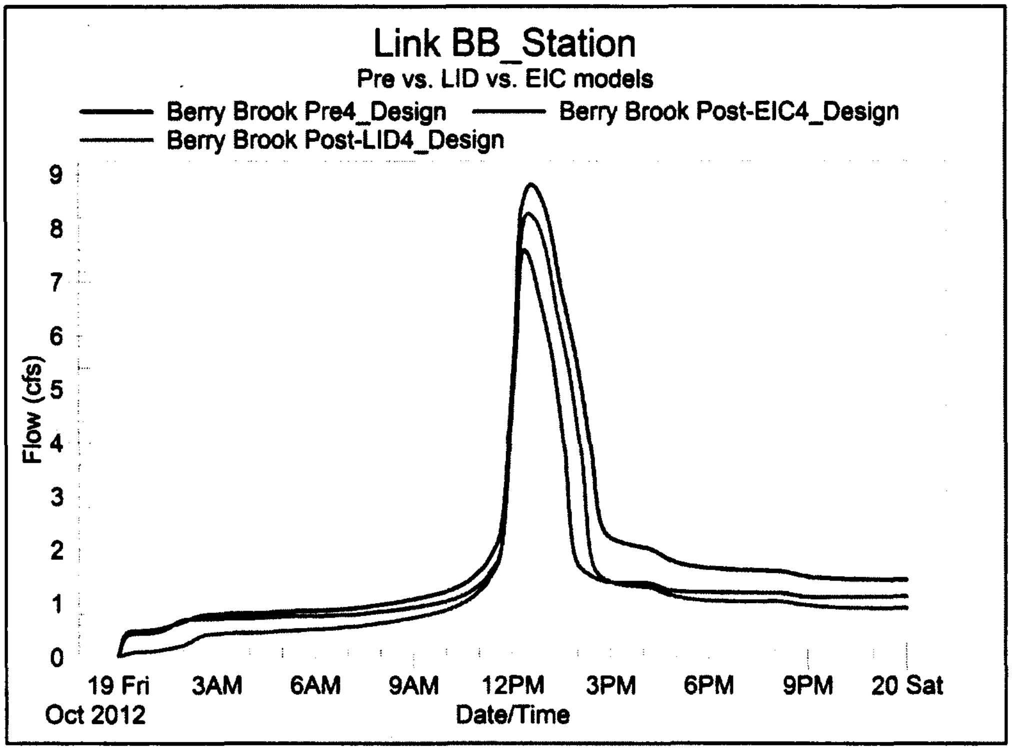


Figure 2-15: Design Storm Modeled Hydrograph

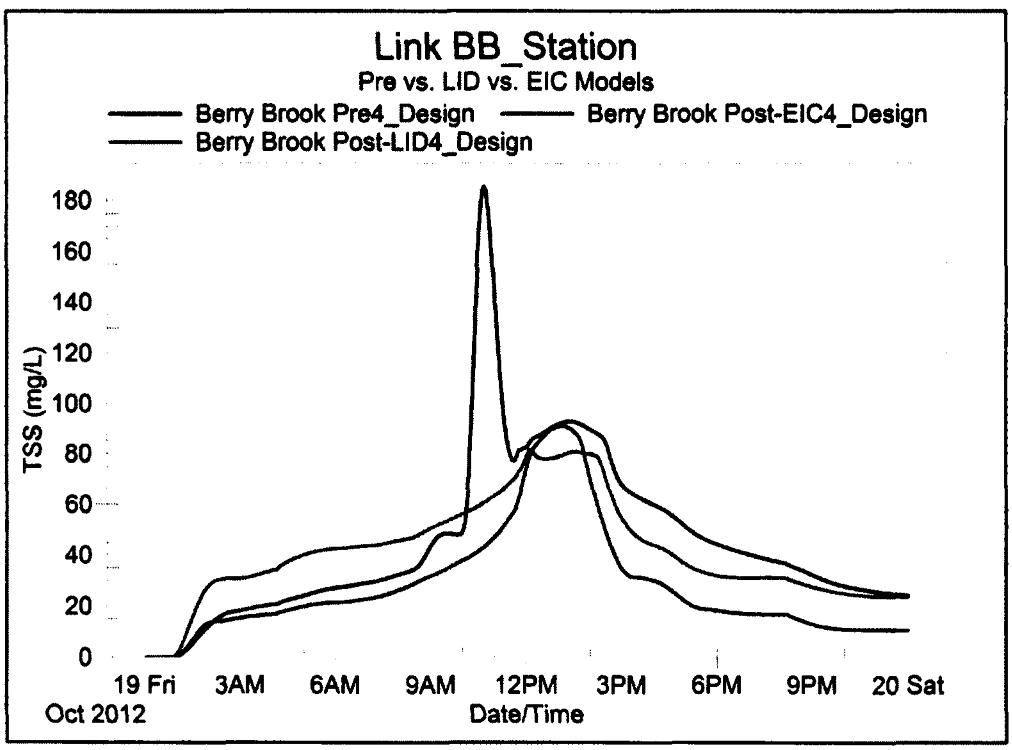


Figure 2-16: Design Storm Modeled Pollutograph

20-Year Continuous - Simulation

All three modeled scenarios were run with a 20 year continuous simulation that included a maximum rainfall event of 7.1 inches and a combined rainfall total of 499.3 inches. Storm event volumes and peaks were statistically tested as matched pairs by modeled scenario (Table 2-17). During larger storm depths and intensities the LID_{model} and EIC_{model} did not necessarily show a reduced peak and volume for every event. For this reason a long-term simulation was necessary in distinguishing overall statistics and watershed performance.

Over the 20 year simulation maximum peak flow for all of the scenarios was approximately 13.5 cfs (Table 2-16). The reason the peak flows were similar was due to the severely undersized culvert at the lower watershed monitoring location that would not uncommonly overtop during large rain events. At this same location the models were built with a culvert and broad crested weir connecting the stream for overtopping purposes. Flows above 13.5 cfs were likely out of bank and were not considered measurable. Overall the LID_{model} reduced total volume by 283,000,000 cubic feet (56%) or 14,100,000 cubic feet per year which includes baseflow, a TSS reduction of 91,000 lbs (28%) or 3,200 lbs per year, a TN reduction of 640 lbs (15%) or 44 lbs per year and a TP reduction of 42 lbs (7%) or 2.1 lbs per year (Table 2-16). Pollutant loads were modeled during storm events only, dry weather pollutant inflows were not considered. Each model had a calibrated dry weather baseflow that varied from about 0.2-0.6 cfs. A comparison of total volume was reassessed by removing a minimum baseflow value for each model. This baseflow reduction was calculated to more closely compare the storm event runoff volumes from each scenario. Analysis of runoff volume showed an LID reduction of 40,000,000 cubic feet (18%) (Table 2-16). The improvement in runoff volume observed with the LID_{model} is likely due to many factors such infiltration, evapotranspiration, and hydrograph transformation effects of the LID systems (the transformed hydrographs extend flows long past natural hydrographs and therefore a numerical reduction in runoff volumes is observed). With the baseflow removed, the EIC_{model} and LID_{model} were in good agreement in terms volume.

Table 2-16: Model Results- 20 Year Long Term Simulation

Model	**Peak Flow cfs**	**Total Volume ft^3 (10^6)**	**TSS lbs (10^3)**	**TN lbs (10^3)**	**TP lbs (10^3)**
Pre	13.5	503	307	4.230	0.602
LID	13.2	220	216	3.590	0.560
EIC	13.6	434	176	2.120	0.338
Δ Pre – LID	0.3	283 (56%)	91.0 (28%)	0.64 (15%)	0.042 (7%)
Annual Reduction		14.1	0.032	0.044	0.0021
Baseflow Reduction					
Pre		225			
LID		185			
EIC		191			
Δ Pre – LID		40.0 (18%)			

To further examine a comparison of the three models a statistical analysis was done on the individual event peaks and volumes. A non-parametric matched paired test of all 1021 events indicated that Pre_{model} peaks and volumes were significantly greater than the LID_{model}; this result was consistent with removed baseflow (Table 2-17). However, this does not imply that all Pre_{model} peaks and volumes were greater than the LID_{model} for every storm event. Binning the storm event data by rainfall depth revealed that Pre_{model} and LID_{model} runoff volumes and peaks were not significantly different at a rainfall depth of 1 inch and greater (Figure 2-17). These results show the importance of evaluating this type of watershed with a long-term data set with a variety of storm depths and intensities to capture overall significance. In summary, the results indicate that the LID_{model} does improve hydrology by peak flow and volume reduction, mainly due to the fact that approximately 70% of storms modeled were 0.5 inches and less.

Table 2-17: Non-Parametric Matched Pair Wilcoxon Signed Rank Analysis of Storm Event Volume and Peak by Modeled Scenario

Model Comparison	n	Test Statistic S	Prob>|S|
ΔPre- LID Volume	1021	251708	<0.0001
ΔLID-EIC Volume	1021	-11989	0.204
ΔPre-LID Peak	1021	197202	<0.0001
ΔLID-EIC Peak	1021	85438	<0.0001
Baseflow Reduction			
ΔPre-LID Volume	1021	179188	<0.0001
ΔLID-EIC Volume	1021	220284	<0.0001
ΔPre-LID Peak	1021	73149	<0.0001
ΔPre-LID Peak	1021	197966	<0.0001

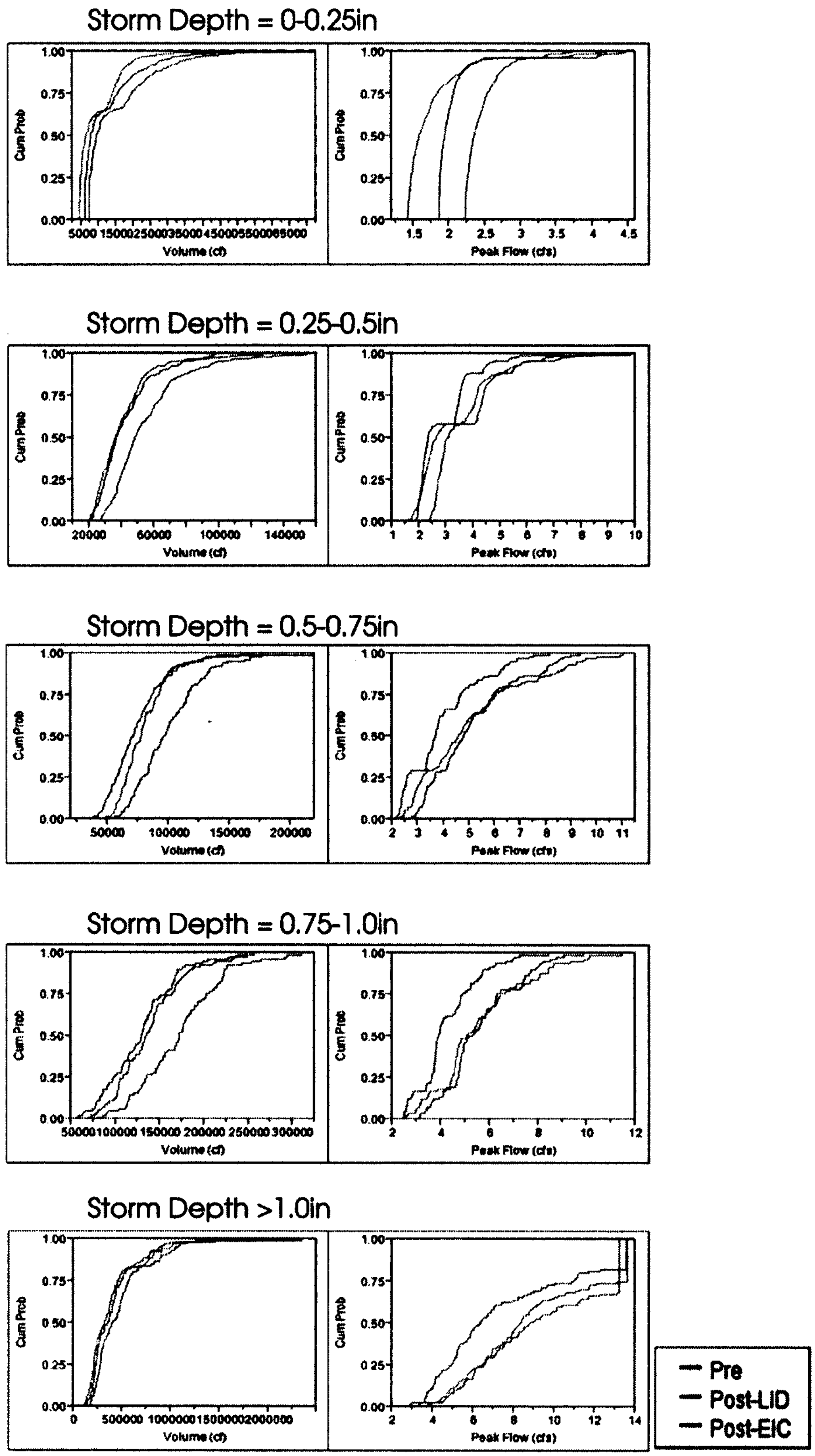


Figure 2-17: Modeled Scenarios of Storm Event Peak and Volume by Model and Binned Rainfall Depths

The EIC_{model} was built to gain a further understanding of pollutant and hydrological response as a function of reduced EIC by LID implementation and watershed improvement efforts. Subcatchment EIC values were computed using the same methods as described in 2.3.4 Data Analysis Methods and Table 2-3: Impervious Cover and Effective Impervious Cover Methods. A matched pair storm event statistical analysis between the LID_{model} and EIC_{model} revealed that total runoff volumes were not significantly different (Table 2-17). However, a comparison of peak flows showed that the EIC_{model} and LID_{model} were statistically different. These results indicate that the EIC_{model} is adequate in simulating runoff volumes but under-approximates peak flows. The discrepancy in peak flow agreement may be due to the difference in generation of runoff and initial abstraction. The LID_{model} generates the same runoff as the Pre_{model} but LID routing reduces peaks. The EIC_{model} has an increased fractional pervious area that would decrease runoff and increase initial abstraction affecting the magnitude of peak flows.

Modeled runoff volumes, TSS, TN, and TP storm event medians were plotted against watershed field measured %EIC (Figure 2-18). The water quality storm event loads were estimated by a non-weighted event mean concentration and runoff volume. The modeled relationship between runoff volumes and %EIC indicates the EIC is a function of runoff volume, similarly this result was observed with the field measured data. Water quality pollutant loads showed a similar relationship but differed from the field measured data (Figure 2-18). The model results suggest that pollutant loads can be described as a function of %EIC (Figure 2-18). The difference in agreement between measured and modeled values may be due to the difficulty in modeling in-stream pollutant removal processes or because the field measured values are not representative of the population due to sample size.

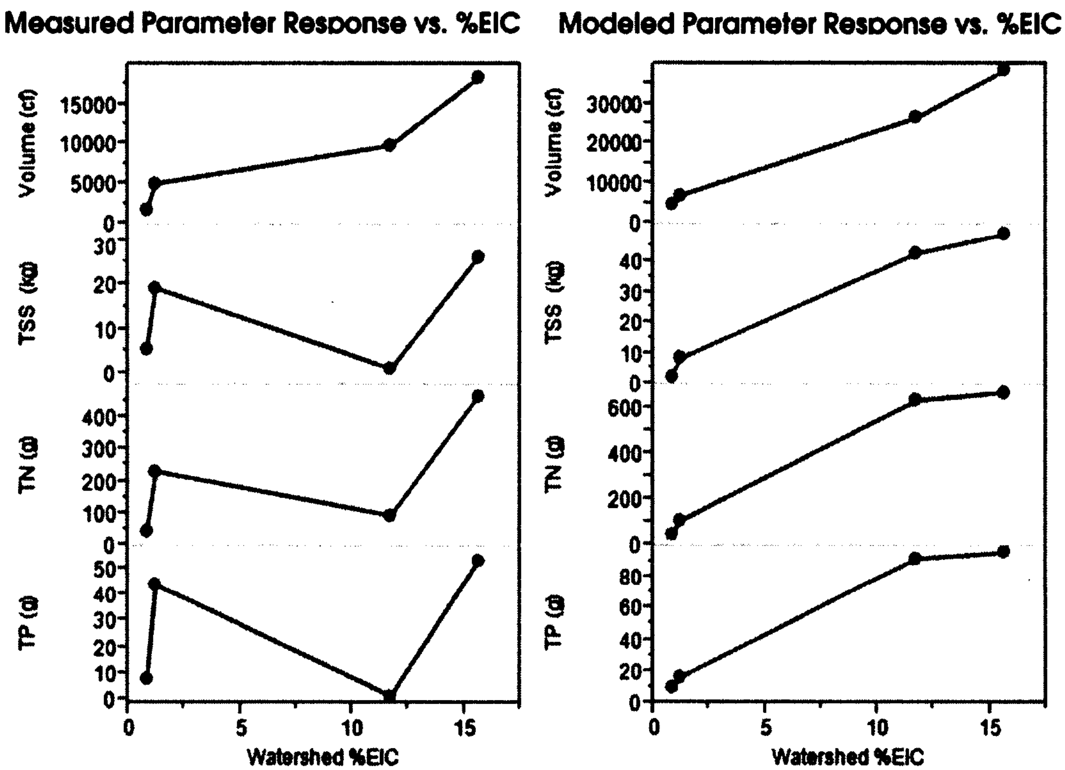


Figure 2-18: Measured and Modeled Storm Event Median Parameter Response by Field Measured Watershed %EIC

Overall, the modeled results indicate that using reduced EIC values could be an acceptable method in modeling and understanding volume reduction. Volume reduction by infiltration and evapotranspiration can ultimately reduce pollutant loads and improve hydrological integrity during storm events and dry weather periods. Reducing or treating EIC with an appropriately sized LID can improve hydrologic integrity.

2.5 Conclusions

This research project examined the reduction or treatment of EIC by LID implementation and watershed improvement efforts with respect to hydrologic and water quality response.

An examination of average, maximum, and minimum daily flows revealed that the LID implementation and stream restoration activities have had a statistically significant quantifiable shift in Berry Brook daily hydrology in the direction of a lesser developed watershed.

A decrease in the $post_{LID}$ storm event runoff volumes was the most significant result of the direct runoff hydrograph analysis. A comparison of median runoff volumes between pre_{LID} and $post_{LID}$ periods shows a reduction of 46%. Mean and median storm flows increased in the upper watershed during the $post_{LID}$ phase. This change could be representative of the stream restoration and changes in the routing of the upper subwatersheds. Overall the changes seemed less apparent at the watershed scale which would be expected since many of the improvements occurred in the upper watershed. These results could be indicative of scaling effects when monitoring at a larger watershed level.

A direct runoff versus rainfall depth linear regression for determining EIC with field measured values showed good agreement with Sutherland's method and a USGS equation at the lower watershed during pre_{LID}. The lower watershed monitoring location had an IC_{pre} that was nearly two times greater than the field measured EIC_{pre}, hence the importance of determining and defining EIC within a watershed. During $Post_{LID}$ EIC values showed moderate agreement with an EPA method and an IC disconnection calculation. The discrepancies between field measured and calculated EIC values were thought to be attributed to the differences in crediting the gravel wetland with volume reduction. For this reason a modification to the IC disconnection method was proposed. The following represents a method for determining IC disconnection by LID treatment as a function of water quality volume treated:

Equation 1: $IC_{post} = IC_{pre} * \left(\frac{WQV_{criteria} - WQV_{design}}{WQV_{criteria}}\right)$,

Where WQV is the water quality volume in inches, $WQV_{criteria}$ represents state criteria for design of LIDs and WQV_{design} symbolizes the treatment depth of the field system. Considering EIC as disconnected when routing runoff through an appropriately sized LID corresponded well for volume reduction.

In the upper watershed Sutherland's method and the USGS equation showed poor agreement to field measured EIC values during pre_{LID}. This discrepancy may have been attributed to the disconnection that the existing wetland was providing prior to improvements. Runoff from approximately 9.6 impervious acres was routed through the existing wetland. The results during $post_{LID}$ were highly variable and there was a lack of fit to the regression. The upper watershed underwent significant improvements and EIC reductions. There were many changes in the routing of the contributing hydrological subwatersheds that may account for the high degree of variability and poor agreement in field measured and empirical relationships for determining pre_{LID} and $post_{LID}$ EIC values.

In addition to the EIC linear regressions, storm event runoff volume versus %EIC were plotted. This relationship indicated that runoff is a function of EIC as expected. This result prompts the question at which threshold of %EIC and runoff volumes does a watershed begin to recover from effects of urbanization? A future examination of biota response with relation to the reduction of EIC could potentially identify the new thresholds. These results support the usage of %EIC as a surrogate for defining stream integrity in a generalized form.

Storm event mean water quality concentration results indicate improvement in TSS, Zn, and TP at the watershed scale during the $post_{LID}$ phase. Ortho-P concentrations at both upper and lower watershed locations indicate an increase during $post_{LID}$. Nitrogen concentrations showed high variability during and little or no change during the period of monitoring. The limited change in nitrogen results may have been affected by lack of LID maturation and plant uptake during the $post_{LID}$ monitoring phase that occurred in the late fall to early winter. Furthermore a potential export of nitrogen from the existing wetland could be large enough to mask the removal effectiveness of the LID systems. A comparison of pollutant loads between pre_{LID} and $post_{LID}$ show significant improvements for all parameters analyzed. These results combine the effects of runoff volume reduction and LID pollutant removal efficiencies. A further comparison between the upper and lower watershed indicated that pollutant response is not solely a function of watershed EIC but also involves in-stream treatment processes and a distribution of storm drain outlets throughout the watershed as well as other factors.

A 20 year rainfall runoff simulation revealed that overall peak flows and volumes were reduced in the LID_{model}. A further examination of individual storm events indicated that Pre_{model} and LID_{model} runoff volumes and peak flows were not statistically different at storm depths of 1 inch and greater. This result is not surprising consider many of the LID systems are designed for a 1 inch water quality volume. Over the 20 year simulation the LID_{model} reduced total volume by 56%, runoff volume by 18%, TSS by 28%, TN by 15%, and TP by 7%. It should be noted that water quality modeling was based on the simple method that assigns pollutant loading characteristics according to land use. The model was not built with buildup and washoff functions that could improve model accuracy. Simulation of other water quality processes such as in-stream removals was not considered.

A comparison of the LID_{model} and EIC_{model} showed that runoff volumes were not statistically different. This result indicates that modeling LID improvements as reduced EIC may be an acceptable method in determining storm event runoff volumes. A relationship between runoff volumes and EIC has been consistently prominent throughout this study in field measured and modeled results. EIC and runoff volume reduction will inherently improve water quality and hydrology.

Overall Berry Brook is positively responding to the reduction of EIC which included LID and restoration efforts. As seen in the long term modeling simulation, identifying specific peak and volume reduction is difficult on the order of months. Even though Berry Brook may experience a significant response shortly after the restoration activities are complete, identifying and measuring the response at a watershed level is a challenge that is best met with long term monitoring.

There is a significant importance to define and identify EIC between watersheds. Examining reduction in EIC as a surrogate for watershed improvement efforts related well with volume reduction. The future challenge is to identify an EIC threshold of when a watershed begins to recover from the effects of urbanization with respect to stream integrity.

Chapter 3

Conclusions

Overall this study examined the effectiveness of LID implementation (reduction of EIC) and watershed improvements with respect to hydrologic, water quality and biota response at the subwatershed and watershed scale. The results indicate that storm event hydrology and water quality parameters are improving in Berry Brook as an effect of the watershed improvement efforts. Baseflow water quality sampling prior to the $post_{LID}$ monitoring period did show that there were continuing concerns with bacteria and high turbidity due to the high iron concentrations. This project also outlined the importance of defining %EIC, the impervious cover that is directly or hydraulically connected to the receiving waterbody and understanding the effects of the reduction of EIC with appropriately sized LID treatment. A modeled examination of the long term impacts of LID and stream restoration efforts indicated significant improvements in runoff volume and pollutant loads over the 20 year simulation. During storm depths of 1 inch and greater the LID_{model} did not show significant improvements in runoff volumes and peak flows. For these reasons it was evident that quantifiable improvements in hydrology and water quality is best met with a long term data set.

Macroinvertebrate samples were collected and analyzed once during pre_{LID} and once during $post_{LID}$. The results were compared to the USGS study, "Effects of Urbanization on Stream Quality at Selected Site in the Seacoast Region in New Hampshire, 2001-03" and are provided in (Appendix D - Biota).

Fish sampling results by the NH Fish and Game are also provided in (Appendix D - Biota). Although a statistical comparison between pre_{LID} and $post_{LID}$ periods was omitted, this data serves to aid in our understanding of true variability and existing fish and macroinvertebrate populations.

Currently much of the environmental investigation in New Hampshire and other states has gone into identifying impairment locations, pollutant stressors, and their respective sources. This information is important as we begin to understand the environmental restoration challenges that lie ahead. Water resources and in particular stormwater management is an area that is targeted for significant improvements in the years to come. To move forward on this objective there needs to be a clear business plan that addresses both the financial aspect and optimized restoration strategies. Many studies have identified the effectiveness and costs of LIDs at the system and site/development scale. The Berry Brook Project has truly been a unique study that has taken cost/benefit to the watershed scale. The findings from this study do not answer all of the questions behind urban restoration, but certainly add to our understanding of watershed and ecosystem response as a result of LID implementation. The synthesis between the reduction of effective impervious cover and hydrologic and water quality response will aid future watershed planners and engineers in optimizing our efforts and understanding benefits. The future question is, at what level of restoration do we begin to recover from the effects of urbanization and what is the EIC threshold that this can be measured by?

Future Study

This study identified that reduction in %EIC by LID implementation and watershed improvements can be related to runoff volume reduction. The future challenge is to identify %EIC stream integrity thresholds with respect to volume reduction. EIC and runoff volume reduction have the potential to serve as a surrogate for water quality and biota response. With continued long term monitoring in Berry Brook this relationship has the potential to be further developed.

The proposed IC disconnection method was applied to the Berry Brook Watershed where good agreement was observed. Further testing of this method at both the system and watershed scale can improve the validity of this equation.

Berry Brook is severely impacted by the natural sources of iron in the groundwater. Further examination and the acute effects based on dry weather and storm event iron concentrations on the biota are necessary to identify whether they can recover based on these limitations. Iron mitigation practices may be necessary to improve biota response.

Many of the findings and ongoing data collection from the Berry Brook Renewal project will sever as a baseline for future studies in this watershed and others. Continued monitoring at Berry Brook will serve to benefit our understanding of restoration efforts within an urban watershed with respect to stream and ecosystem response.

During the watershed modeling phase I had the opportunity to work with some of the engineers and developers behind the latest PCSWMM software from

Computational Hydraulics International (CHI). This modeling software proved to be very powerful and useful in simulating rainfall runoff in the Berry Brook watersheds. Urban watershed restoration is field that will continually grow and using tools such as modeling software can improve our understanding of LID effects in the long term. The engineers at CHI immediately took an interest in the Berry Brook project an asked how the software can be improved on based on our objectives. More recently the software engineers have been developing platforms for water quality and LID modeling. For this reason certain limitations existed when modeling LIDs and water quality. The findings and limitations from this project will be put forth to the continued development of this software.

Limitations

This project aimed to quantify changes on a watershed scale. Although the Berry Brook watershed is of manageable size, this task poses many challenges that cannot be controlled throughout the period on monitoring. Watersheds change year to year based on climate, watershed activities, and human behavior. For these reasons visiting the watershed on a daily or weekly basis is important in attempting to understand these changes that the watershed undergoes.

A challenge that is always presented in field research is period of monitoring and depth of data. In our case a longer period of monitoring record pre_{LID} and $post_{LID}$ watershed improvements would improve statistical comparisons. Our $post_{LID}$ monitoring period was governed by the completion of LID installs later in the year than was expected. Consequently time to parameter response and measuring a response are suggestively different concepts that require significant data sets in order to distinguish.

Part of the data analysis and modeling techniques relied on rainfall data that was collected approximately 5 miles from the Berry Brook Watershed. Rainfall depths and intensities can significantly vary spatially. For this reason the linear regression of runoff versus rainfall depth and model calibration was limited to available data.

Certainly a limitation to the biota response may be the high concentrations of iron within the stream. This may be a limitation until groundwater sources are depleted or mitigation activities correct the problems.

In the upper watershed stream restoration efforts day lighted a significant portion of the stream which was previously linked by culverts. Currently there still exists connection between the headwaters and the Roosevelt outfall. Although the culvert is partially blocked and limited flows are discharging, baseflow hydrology may be impacted when the culvert is fully disconnected. One of the main monitoring locations at the lowest portion of the watershed is Station drive. At this location nearly an entire 185 acre watershed is routed through a 12 inch culvert and relatively low stream banks. During the period of monitoring it was not uncommon to have culvert overtopping and out of bank flows during large storm events. These issues along with culvert surcharge can make it difficult to make accurate estimates when describing hydrologic peaks and volumes during observation and modeling.

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Appendices

The appendices are intended to supplement the results presented in Chapters 2 and 3. Appendix A-Berry Brook Watershed provides additional watershed land use information, other monitoring locations that were used throughout the study and their respective periods of monitoring and parameters collected, as well an LID implementation schedule. Appendix B-Hydrology provides direct runoff vs. rainfall linear regression confidence interval tests for comparisons of pre_{LID} and $post_{LID}$, and direct runoff hydrograph parameter data for all storms monitored for the upper and lower watershed. Appendix C-Water Quality provides supplemental water quality baseflow data that was used in qualitative analysis and the raw concentration and load data for all analyzed storms. Appendix D-Biota includes additional data and information for both macroinvertebrates and fish. This section outlines specific methods, locations, and findings. The fish report is provided by the NH Fish and Game. Appendix E-Model primarily describes model parameter calibration and results. Appendix F-LID Drawings are intended to provide examples of the type of LID systems that were implemented within the watershed. These include a subsurface gravel wetland, bioretention system, and a tree filter.

Appendix A - Berry Brook Watershed

Other Monitoring Locations

All collected parameters and periods of monitoring by location are shown in the Berry Brook Monitoring Overview table below and can be seen in Figure 2-1.

Central Ave (43°12′54.45″N, 70°52′46.17″W-NAD 83)

Central Ave and the Hanaford's parking lot combined contribute approximately 11.1 acres of stormwater runoff to the headwaters of Berry Brook (Figure 2-1, Figure 2-2). Currently the stormwater is routed through a subsurface gravel wetland that outlets to another series of existing and new wetland improvements. During the pre$_{UD}$ phase continuous data was being monitored at the outlet of the 36″ reinforced concrete pipe that collects the drainage from the Hanaford's parking lot. Currently the sampling instrument is located at the outfall of the gravel wetland. Monitoring period is shown in the Berry Brook Monitoring Overview Table.

Maple St (43°12′29.54″N, 70°52′43.39″W -NAD 83)

This location is the true divide between the upper and lower watershed of Berry Brook. This site serves as the midpoint between the headwaters and the discharge location into the Cocheco River. Monitoring period and parameters are shown in Berry Brook Monitoring Overview Table.

Hough St (43°12′16.70″N, 70°52′47.78″W-NAD 83)

Hough is a street crossing in the lower third of the watershed. Monitoring at this site includes continuous data, invertebrate and fish sampling.

College Brook, Durham NH (43°07'58.58N, 70°55'37.62"W-NAD 83)

College Brook was intended to serve as a control stream for the macroinvertebrate results. College Brook was chosen as a control because of its similarities to Berry Brook in watershed size and degree of impervious cover.

Berry Brook Monitoring Overview

Location (Stream-mile)	Continuous Data: Depth, Conductivity, Temp		Composite Sampling: SSC, TSS, TN, TKN, NO3, NO2, NH3, PO4, TP, TPH-D, Mn, Zn, Fe, pH, DO	Composite Sampling:TSS, TN, TKN, NO3, NO2, NH3, PO4, TP, Mn, Zn, Fe, pH, DO	Fish Sampling		Invertebrate Sampling	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Central Ave. (0.00)	(6/2/11-7/11/11)	(10/19/12-Current)		5x(10/19-12/17/12)				
Roosevelt Ave. (0.25)	(6/2/11-10/19/11)	(10/19/12-Current)	10x-(7/6/11-10/13/11)	5x(10/19-12/17/12)			1x-10/19/11	
Maple St. (0.50)		(10/19/12-Current)	1x-(10/19/11)	5x(10/19-12/17/12)	1x-5/26/11	1x-10/15/12	1x-10/19/11	1x-10/25/12
Hough St. (0.77)	(10/7/11-10/19/11)	(10/19/12-Current)			1x-5/26/11	1x-10/15/12	1x-10/19/11	
Sixth St. (0.87)					1x-5/26/11	1x-10/15/12	1x-10/19/11	
Station Dr. (1.16)	(7/11/11-10/19/11)	(10/19/12-Current)	13x-(6/11/11-10/19/11)	4x (10/27-12/7/13)				
College Brook(Control)							1x-10/26/11	1x-10/25/12
Wetland Weir Wall		(10/19/12-Current)						
Stream Restoration								1x-10/30/12

Land Use by Impervious Cover Type

Land Use	Perv.	Roads	Driveways	Compacted gravel/soil	Parking	Rooftops	Other asphalt e.g. sidewalks	Other IC (e.g. decks, patios)	Impervious Total	%IC
	Acres									
1120 - Multi-family, low rise apartments	8.69	0.34	2.39	0.11	0.00	2.27	0.42	0.17	5.70	7.8%
1130 - Single family/duplex	79.96	2.26	7.24	0.32	0.70	10.86	0.97	0.83	23.18	55.8%
1210 - Commercial retail	0.76	0.21	0.00	0.00	4.95	1.50	0.05	0.00	6.71	4.0%
1220 - Commercial wholesale	0.45	0.03	0.93	0.00	0.53	1.27	0.04	0.00	2.80	1.8%
1230 - Services	0.12	0.03	0.02	0.00	0.35	0.08	0.00	0.00	0.48	0.3%
1250 - Government	0.70	0.01	0.23	0.22	0.00	0.13	0.00	0.00	0.59	0.7%
1260 - Institutional	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.0%
1270 - Educational	5.88	0.05	0.69	0.00	0.41	1.40	0.11	0.34	3.00	4.8%
1442 - Road right-of-way	0.49	11.32	0.73	0.01	0.00	0.00	0.09	0.00	12.16	6.8%
1690 - Other mixed uses	0.12	0.00	0.07	0.00	0.05	0.06	0.00	0.00	0.19	0.2%
4000 - Forest Land	29.18	0.01	0.03	0.00	0.00	0.02	0.00	0.00	0.06	15.8%
5000 - Water	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.2%
6000 - Wetlands	1.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.0%
7600 - Disturbed Land	0.90	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.36	0.7%
Total	**129.4**	**14.34**	**12.35**	**1.02**	**6.98**	**17.59**	**1.68**	**1.34**	**55.30**	29.9%

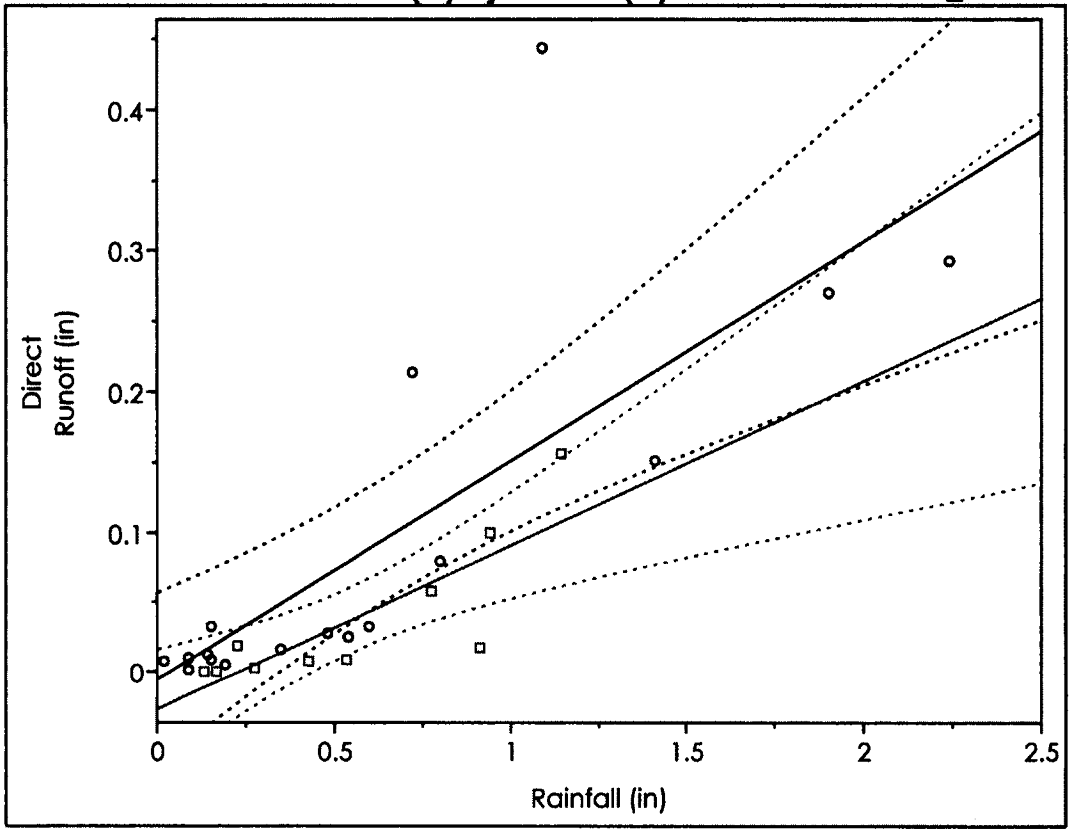
***Land use breakdown by IC type, results are provided by the UNHCRSC**

Monitoring and LID Implementation Schedule

Task Name	Approx. Duration	Start	Finish
Pre Construction Monitoring	**126 days**	**Thu 6/2/11**	**Wed 10/5/11**
Interim Monitoring	**358 days**	**Thu 10/27/11**	**Thu 10/18/12**
Stream Restoration	**291 days**	**Tue 8/16/11**	**Fri 6/1/12**
Demolition	13 days	Tue 8/16/11	Sun 8/28/11
Excavation	99 days	Wed 9/7/11	Wed 12/14/11
Page Connection	5 days	Tue 9/20/11	Mon 9/26/11
C-Channel and Floodplain	20 day	Thur 10/20/11	Wed 11/9/11
A-Channel	26 days	Wed 11/9/11	Wed 12/14/11
Pumping/Syphon	16 days	Wed 11/23/11	Wed 12/14/11
Weir Wall	1 day	Tue 10/25/11	Tue 10/25/11
Stream Restoration Online	60 days	Thu 12/15/11	Sun 2/12/12
Weir Plate	1 day	Fri 6/1/12	Fri 6/1/12
LID Phase I	**106 days**	**Wed 6/1/11**	**Wed 10/26/11**
Horne St. School	5 days	Thu 6/9/11	Wed 6/15/11
Page Ave.	5 days	Tue 9/20/11	Mon 9/26/11
Snow Ave	23 days	Mon 9/26/11	Wed 10/26/11
Horne St. School II	3 days	Mon 10/24/11	Wed 10/26/11
LID Phase II	**232 days**	**Wed 2/29/12**	**Thu 10/18/12**
Gravel Wetland	66 days	Mon 2/27/12	Wed 5/2/12
Lowell Ave.	15 days	Tue 7/24/12	Tue 8/7/12
Upper Horne St.	24 days	Sat 9/15/12	Mon 10/8/12
Glencrest	2 days	Wed 10/17/12	Thu 10/18/12
Post Construction Monitoring	**74 days**	**Thu 10/18/12**	**Mon 12/31/12**

Appendix B - Hydrology

Bivariate Fit of Direct Runoff (in) By Rainfall (in) – Lower Watershed_Station



Linear Fit Phase=="Pre-LID (IC=30.1%, EIC=15.6%)"
Linear Fit Phase=="Post-LID (IC=18.9%, EIC = 11.2%)"

Linear Fit Phase=="Pre-LID (IC=30.1%, EIC=15.6%)"

Direct Runoff (in) = -0.004391 + 0.1560643*Rainfall (in)

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept		-0.004391	0.029102	-0.15	0.8821
Rainfall (in)		0.1560643	0.031973	4.88	0.0002*

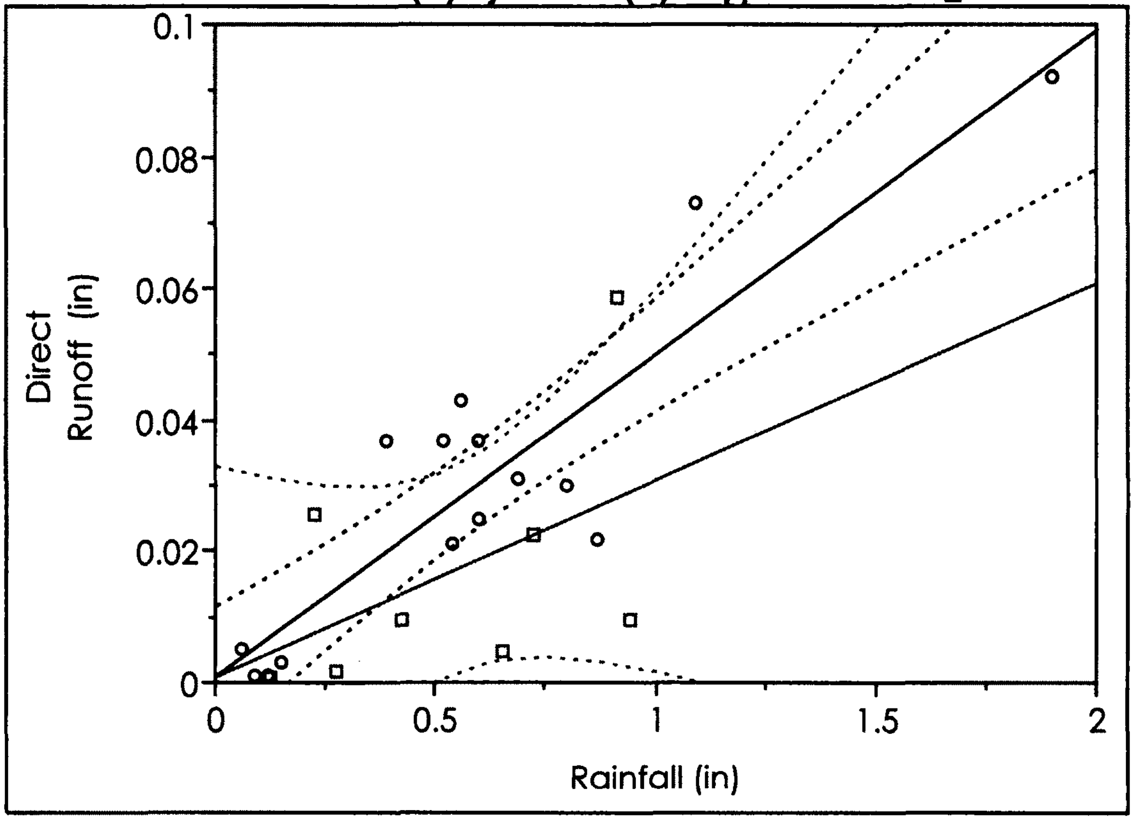
Linear Fit Phase=="Post-LID (IC=18.9%, EIC = 11.2%)"

Direct Runoff (in) = -0.025993 + 0.1172996*Rainfall (in)

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept		-0.025993	0.018752	-1.39	0.2031
Rainfall (in)		0.1172996	0.028848	4.07	0.0036*

Bivariate Fit of Direct Runoff (in) By Rainfall (in) – Upper Watershed_Roosevelt



Linear Fit Phase=="Pre-LID (IC=39.4%, EIC=4.9%)"
Linear Fit Phase=="Post-LID (IC=8.7%, EIC=3.0%)"

Linear Fit Phase=="Pre-LID (IC=39.4%, EIC=4.9%)"
Direct Runoff (in) = 0.0011051 + 0.0491564*Rainfall (in)

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept		0.0011051	0.004946	0.22	0.8267
Rainfall (in)		0.0491564	0.006584	7.47	<.0001*

Linear Fit Phase=="Post-LID (IC=8.7%, EIC=3.0%)"
Direct Runoff (in) = 0.0010449 + 0.0300331*Rainfall (in)

Parameter Estimates

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept		0.0010449	0.013108	0.08	0.9391
Rainfall (in)		0.0300331	0.021532	1.39	0.2125

Storm Event Direct Runoff Hydrograph Parameters-Lower Watershed-Station

Storm	Date	Mean (cfs/in)	Median (cfs/in)	Std Dev	Skew	Kurtosis	Peak (cfs/in)	Volume (cf)
pre1	7/14/2011	66.2	57.5	53.0	0.3	-1.1	149.1	18414
pre2	7/26/2011	44.9	22.0	45.6	0.6	-1.5	118.0	6600
pre3	8/7/2011	33.7	39.8	23.6	0.7	1.7	100.8	22345
pre4	8/8/2011	46.2	11.6	69.8	1.9	3.3	243.8	8252
pre5	8/9/2011	37.2	27.6	31.8	0.7	-0.6	101.5	17266
pre6	8/15/2011	8.6	7.0	7.8	1.0	0.3	10.1	181312
pre7	8/21/2011	62.4	37.8	83.8	1.7	1.5	230.3	22341
pre8	8/25/2011	56.3	50.3	42.3	0.0	-1.6	118.5	6075
pre9	8/25/2011	79.6	92.2	66.3	0.1	-1.4	180.6	5040
pre10	8/27/2011	10.3	5.9	9.8	1.1	0.9	44.5	196946
pre11	9/6/2011	33.6	36.5	17.3	-0.7	-0.6	54.1	3902
pre12	9/7/2011	6.0	3.4	8.2	2.7	8.3	43.5	101610
pre13	9/20/2011	38.9	25.4	32.1	0.6	-1.1	97.0	964
pre14	9/22/2011	15.2	14.1	12.1	0.4	-0.8	43.5	11267
pre15	9/23/2011	18.1	10.2	21.0	2.0	3.2	79.8	53550
pre16	9/29/2011	56.1	35.2	54.0	1.3	1.0	179.4	143672
pre17	10/2/2011	12.6	9.5	15.2	1.5	1.7	65.3	298023
post1	10/19/2012	31.0	23.6	23.7	1.2	0.2	87.1	7070
post2	10/20/2012	45.6	23.8	50.2	1.0	-0.1	168.5	39995
post3	10/29/2012	16.9	11.1	13.8	1.2	0.4	56.7	105371
post4	10/30/2012	120.2	125.5	82.1	0.3	-0.4	276.1	13774
post5	11/8/2012	16.3	10.4	13.2	0.8	-0.4	47.1	12780
post6	11/13/2012	67.5	78.4	33.0	-0.6	-0.6	117.4	619
post7	12/2/2012	141.3	8.7	15.4	0.9	-0.2	53.3	1021
post8	12/8/2012	23.8	23.3	15.5	0.0	-1.3	51.9	3132
post9	12/10/2012	20.3	17.2	19.1	0.3	-1.5	53.1	5939
post11	12/21/2012	17.6	7.0	20.7	1.0	-0.5	63.4	67982

Storm Event Direct Runoff Hydrograph Parameters-Upper Watershed-Roosevelt

Storm	Date	Mean (cfs/in)	Median (cfs/in)	Std Dev	Skew	Kurtosis	Peak (cfs/in)	Volume (cf)
pre1	6/9/2011	34.3	24.9	45.0	1.6	2.6	109.5	5223
pre2	6/11/2011	8.8	5.4	7.4	0.7	-0.8	23.5	6266
pre3	6/12/2011	25.2	26.3	20.5	-0.1	-1.5	52.7	6266
pre4	6/23/2011	24.4	16.1	29.0	1.5	2.0	81.2	205
pre5	6/25/2011	23.4	6.9	34.1	1.4	0.4	85.0	7211
pre7	7/25/2011	18.5	12.1	21.5	2.1	5.4	71.2	768
pre9	7/26/2011	10.2	11.0	5.8	-0.3	-0.8	19.3	6306
pre11	8/9/2011	22.0	27.4	18.3	-0.2	-2.1	44.1	3532
pre12	8/15/2011	2.6	1.5	2.9	1.5	2.5	13.5	15457
pre14	8/25/2011	37.4	27.0	46.4	0.7	-2.4	95.7	424
pre15	9/7/2011	9.7	8.7	6.5	0.3	-0.8	21.5	3683
pre16	9/20/2011	18.1	16.3	12.5	-0.2	-1.2	33.9	136
pre17	9/23/2011	4.7	3.1	5.1	2.0	4.2	23.0	5110
pre18	9/29/2011	15.3	13.4	13.4	0.5	-0.6	39.8	4174
pre19	10/2/2011	4.2	3.2	3.4	1.2	1.1	14.0	12215
post1	10/20/2012	92.4	13.3	152	1.8	3.1	382.0	807
post2	10/29/2012	12.1	11.0	8.1	0.3	-0.7	30.1	1691
post3	10/30/2012	74.7	71.3	68.3	0.1	-1.9	168.4	4443
post4	11/8/2012	7.7	7.4	4.1	0.0	-0.8	15.7	9995
post5	11/13/2012	42.8	49.1	34.0	0.0	-1.4	97.2	109
post6	12/8/2012	19.7	20.5	13.0	0.1	-0.7	43.5	392
post7	12/10/2012	11.0	9.8	6.0	0.0	-1.4	21.1	1669
post9	12/21/2012	47.3	37.0	48.7	1.2	1.3	157.3	3955

Appendix C - Water Quality

Dry weather grab sample taken a various locations 4/16/2012

	Parameters (mg/L)										
Location	**Fe**	**Mn**	**Zn**	**NH3+**	**NO3**	**NO2**	**TKN**	**TN**	**PO4+**	**TP**	**TSS**
Central	7.5	2	BDL	BDL	BDL	BDL	1.2	1.2	0.018	0.01	18
Roosevelt	11	0.91	0.01	BDL	BDL	BDL	1.3	1.3	0.018	0.05	25
Maple	7.3	0.54	BDL	BDL	0.2	BDL	0.7	0.9	0.019	0.05	27
Station	0.98	0.32	BDL	BDL	0.2	BDL	0.7	0.9	0.018	BDL	2

Bacteria results by location and sample type

	Sample	**E. Coli (cfu/100mL)**			
Date	**Wet/Dry**	**Central**	**Roosevelt**	**Maple**	**Station**
10/17/2011	Wet	-	520	-	1080
10/30/2011	Wet	-	-	560	1000
7/31/2012	Dry	50	10	10	130
8/13/2012	Dry	150	30	80	310
8/28/2012	Wet	50	1900	N/A	1030
9/13/2012	Dry	10	10	40	60

Iron and Manganese Storm Event Mean Concentrations during Post$_{LID}$ Monitoring

	Iron (mg/L)				Manganese (mg/L)			
Date	C	R	M	S	C	R	M	S
10/19/2012	3.3	110.00	44.00		0.56	0.51	0.57	
11/8/2012	3	12.00	9.40	1.7	0.48	0.65	0.38	0.20
11/13/2012	4.3	8.80	4.40	0.96	0.72	0.83	0.54	0.40
12/2/2012	5.7	21.00	6.40	1.7	0.84	0.88	0.55	0.42
12/7/2012	3.6	15.00	12.00	6.2	0.34	0.75	0.50	0.46

*C-Central, R-Roosevelt, M-Maple, S-Station

Water Quality Raw Data – Lower Watershed-Station Pre$_{LID}$

Date	TSS (mg/L)	TSS (Kg)	TN (mg/L)	TN (g)	TKN (mg/L)	TKN (g)	NO3 (mg/L)	NO3 (g)	TP (mg/L)	TP (g)	Ortho-P (mg/L)	Ortho-P (g)	Zn (mg/L)	Zn (g)
6/11/2011	20	N/A	0.8	N/A	0.6	N/A	0.2	N/A	0.03	N/A	0.005	N/A	0.01	N/A
6/18/2011	62	N/A	1.2	N/A	1.0	N/A	0.2	N/A	0.11	N/A	0.005	N/A	0.03	N/A
7/6/2011	20	N/A	1.2	N/A	0.9	N/A	0.3	N/A	0.04	N/A	0.010	N/A	0.02	N/A
7/13/2011	280	146	2.1	1095	1.7	886.4	0.4	208.6	0.35	182	0.005	2.6	0.05	26.1
7/25/2011	45	8	1.3	243	1.0	186.9	0.3	56.1	0.07	13.1	0.020	3.7	0.02	3.7
7/26/2011	57	N/A	1.0	N/A	0.7	N/A	0.3	N/A	0.10	N/A	0.140	N/A	0.02	N/A
7/29/2011	59	N/A	1.0	N/A	0.7	N/A	0.3	N/A	0.09	N/A	0.005	N/A	0.02	N/A
8/6/2011	61	39	1.1	696	0.8	506.2	0.3	189.8	0.13	82.3	0.005	3.2	0.03	19.0
8/9/2011	29	14	0.3	122	0.3	122.2	0.2	97.8	0.05	24.4	0.005	2.4	0.01	4.9
8/15/2011	58	298	1.1	5647	0.8	4107	0.3	1540	0.10	513	0.005	25.7	0.02	102
9/6/2011	19	2.1	0.3	27.6	0.3	27.6	0.2	22.1	0.04	4.4	0.005	0.6	0.01	1.1

Water Quality Raw Data-Lower Watershed-Station-Post$_{LID}$

Date	TSS (mg/L)	TSS (Kg)	TN (mg/L)	TN (g)	TKN (mg/L)	TKN (g)	NO3 (mg/L)	NO3 (g)	TP (mg/L)	TP (g)	Ortho-P (mg/L)	Ortho-P (g)	Zn (mg/L)	Zn (g)
11/8/2012	25	9.0	1.0	361.9	0.6	217.1	0.4	144.8	0.03	10.9	0.015	5.4	0.01	3.6
11/13/2012	5	0.1	0.8	14.0	0.5	8.8	0.3	5.3	0.01	0.1	0.017	0.3	0.01	0.2
12/2/2012	8	0.2	1.3	37.6	1.1	31.8	0.2	5.8	0.01	0.3	0.007	0.2	0.01	0.3
12/7/2012	25	2.2	1.7	150.7	1.4	124.1	0.3	26.6	0.03	2.7	0.017	1.5	0.01	0.9

Water Quality Raw Data – Upper Watershed-Roosevelt PreLID

Date	TSS (mg/L)	TSS (Kg)	TN (mg/L)	TN (g)	TKN (mg/L)	TKN (g)	NO3 (mg/L)	NO3 (g)	TP (mg/L)	TP (g)	Ortho-P (mg/L)	Ortho-P (g)	Zn (mg/L)	Zn (g)
6/18/2011	180	32	2.9	514.5	2.7	479.0	0.2	35.5	0.5	81.6	0.005	0.9	0.03	5.3
7/6/2011	48	N/A	0.8	N/A	0.5	N/A	0.3	N/A	0.1	N/A	0.005	N/A	0.01	N/A
7/13/2011	400	N/A	2.5	N/A	2.1	N/A	0.4	N/A	0.4	0.4	0.005	N/A	0.03	N/A
7/25/2011	210	5	2.5	54.4	2.2	47.8	0.3	6.5	0.4	8.0	0.010	0.2	0.02	0.4
7/26/2011	380	68	2.1	375.0	1.8	321.4	0.3	53.6	0.4	73.2	0.005	0.9	0.02	3.6
7/29/2011	130	N/A	1.4	N/A	1.1	N/A	0.3	NA	0.2	N/A	0.005	N/A	0.02	N/A
8/9/2011	73	7	0.9	90.0	0.8	80.0	0.1	10.0	0.2	15.0	0.005	0.5	0.01	1.0
8/15/2011	200	88	1.4	612.8	1.2	525.2	0.2	87.5	0.3	148	0.010	4.4	0.02	8.8
9/6/2011	33	3	0.8	83.4	0.7	73.0	0.1	10.4	0.1	7.3	0.005	0.5	0.01	1.0

Water Quality Raw Data – Upper Watershed-Roosevelt PostLID

Date	TSS (mg/L)	TSS (Kg)	TN (mg/L)	TN (g)	TKN (mg/L)	TKN (g)	NO3 (mg/L)	NO3 (g)	TP (mg/L)	TP (g)	Ortho-P (mg/L)	Ortho-P (g)	Zn (mg/L)	Zn (g)
10/19/2012	750	17	3.1	70.9	2.5	57.1	0.6	13.7	0.6	14.6	0.016	0.4	0.04	0.9
11/8/2012	39	11	1.0	283	0.7	198.1	0.3	84.9	0.1	17.0	0.017	4.8	0.01	2.8
11/13/2012	27	0.1	1.1	3.4	0.9	2.8	0.2	0.6	0.1	0.2	0.018	0.1	0.01	0.0
12/2/2012	140	N/A	1.9	N/A	1.7	N/A	0.1	N/A	0.2	N/A	0.008	N/A	0.02	N/A
12/7/2012	40	0.4	1.9	21.1	1.7	18.9	0.2	2.2	0.1	1.1	0.016	0.2	0.01	0.1

Appendix D - Biota

Macroinvertebrate Sampling Overview

Method: 5 kick net sub-samples were composited into 1 sample. Sub-samples were taken at representative riffle sections and kick net procedure was done for approximately 60 seconds.

Locations: Macroinvertebrate sample dates and locations are outlined in Berry Brook Monitoring Overview Table. Sub-samples were taken from riffle sections directly above culvert locations except for the College Brook site and stream restoration. At College Brook sub-samples were taken directly below the Mill Road culvert. Sub-sampling for the stream restoration site was taken as a reach-wide sub-sample. In particular, 3 sub-samples were taken from the step pool sequence. 1 sub-sample was taken at a riffle in the lower gradient section below the at-grade crossing. 1 sub-sample was taken at the riffle below the wetland weir wall and log vane grade control structure.

Sampling Device: 500µm mesh square foot Surber Sampler

Collection Bottles: 1L plastic Nalgene-type bottles with wide mouth opening with screw on top. Bottles were labeled with site number, date, and preservative. Bottles were filled with 2/3rds preservative prior to collection.

Preservative: 70% Ethanol

Habitat: Habitat assessment was completed using the field data sheet found here:

http://water.epa.gov/scitech/monitoring/rsl/bioassessment/upload/2001_03_08_monitoring_rbp_app_a.pdf

Other Notes: -Sampling was completed during baseflow conditions for all sites except the stream restoration area which was taken a day after a storm event for adequate flow.

Fish Sampling Overview

New Fish and Game electrofished Berry Brook at 3 locations during 2 dates, 5/26/2011 and 10/15/2012. Results and survey comments are provided by NH Fish and Game.

Survey 1: Ash Street (43.20701 -70.87919)

Site Description: One pass starting directly upstream of the Ash St. crossing

Survey Length/Survey Effort: 79meters/289 seconds

Survey Comments: Orange algae covering stream bottom. Bottom mostly sand. Abundant trash. One section had eroding banks with soil washing into the stream. Crossings at both ends of reach. There's an inlet perch at the downstream end of the cement culvert (long- ~100ft) on Ash Street. The survey ended at a covered section of Berry Brook (perhaps and old crossing) behind a residential house on Maple St. This "crossing" is essentially an extension of someone's yard.

Survey 2: Sixth Street (43.20374 -70.88046)

Site Description: One pass starting directly upstream of the Sixth St crossing

Survey Length/Survey Effort: 100meters/586 seconds

Survey Comments: Stream is very entrenched with minimal or now buffer. Much of this section has lawn up to the water's edge. Stream has cut down up to two feet in some locations. Very turbid with iron color. Most fish were found congregated in a deeper bend in the stream. Upper section of reach was more forested with better canopy cover.

Survey 3: Hough Street (43.20462 -70.87991)

Site Description: One pass starting directly upstream of the Hough St. crossing

Survey Length/Survey Effort: 63meters/381 seconds

Survey Comments: Surveyed up to next crossing (private/industrial crossing?). Brook trout appear to be hatchery fish because of pectoral fin wear on both cohorts. It is expected that the hatchery brook trout were from fish stocked within the Cocheco River. This shows the potential for fish to use Berry Brook for thermal refuge during warmer times. Much more canopy cover in this section-close to 100%. Lots of garbage found in this section. Hough Rd. crossing consists of three small culverts (two are clogged with debris and no flow is going through them. The single culvert with flow appears to be suitable for passage. Stream is still entrenched in some places here. Stream is very turbid and becomes completely brown when walking through it. It likely gets this way after storm events as well.

Biota Results

Macroinvertebrate Analysis by Monitoring Location

	Total Abundance		% EPT		Habitat Score		HBI		% Tolerant		% Intolerant	
Site	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Maple St.	56	26	11	5	130	126	17	9	9	31	0	15
Stream Restoration	-	251	-	21	-	155	-	68	-	82	-	6
College Brook	223	79	23	8	124	113	61	17	65	38	9	13
Roosevelt	36	N/A	9	N/A	123	N/A	14	N/A	25	N/A	6	N/A
Hough St.	165	N/A	22	N/A	129	N/A	14	N/A	15	N/A	21	N/A
Sixth St	68	N/A	19	N/A	100	N/A	20	N/A	34	N/A	9	N/A

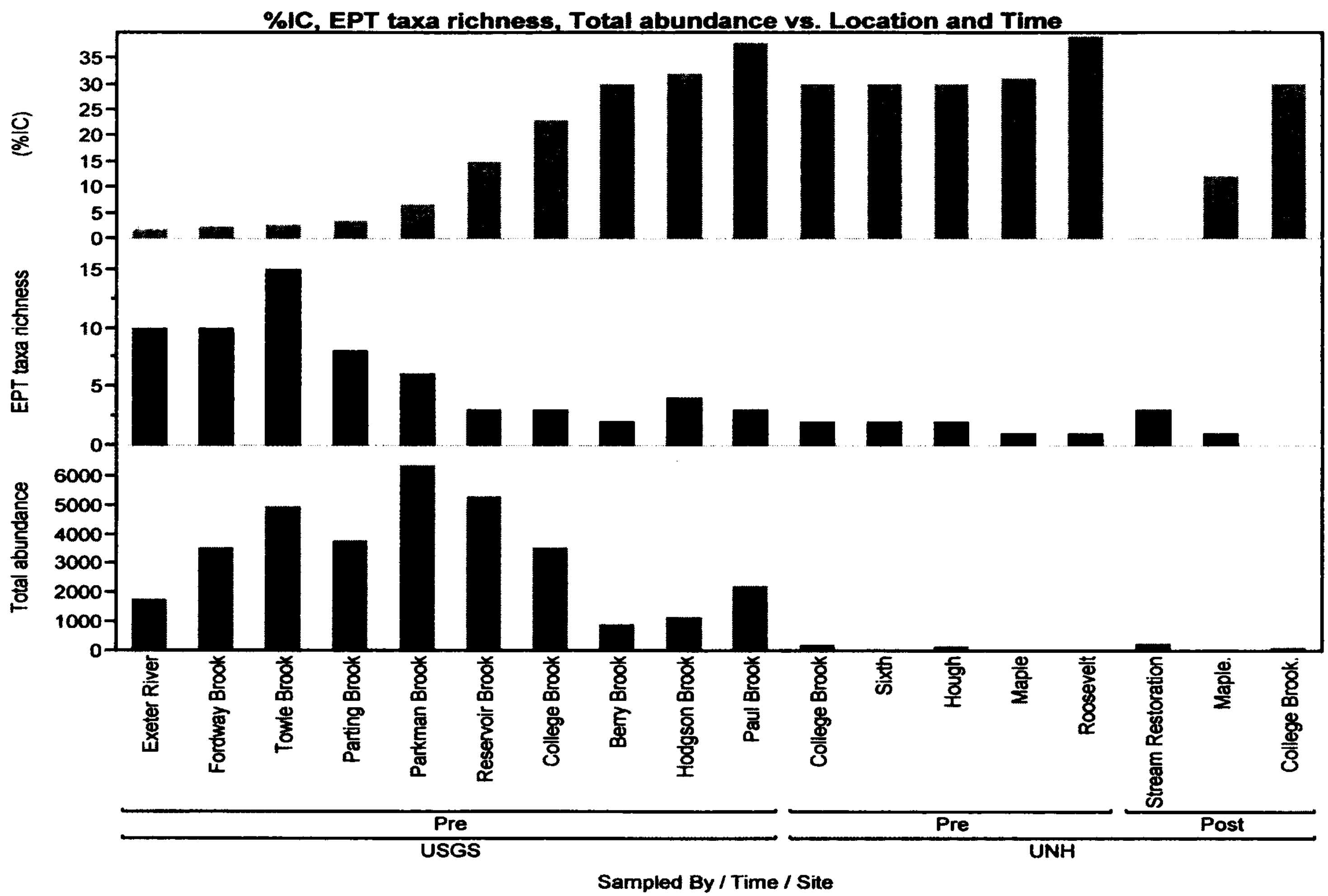
Taxa Measures

	All Taxa		EPT Taxa		Chironomidae = 1		% Chironomidae		% Taxa non-insects	
Site	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Maple St.	11	5	1	1	11	5	9	20	45	40
Stream Restoration	-	21	-	3	-	17	-	24	-	33
College Brook	23	8	2	0	14	8	43	75	30	75
Roosevelt	9	N/A	1	N/A	7	N/A	33	N/A	44	N/A
Hough St.	22	N/A	2	N/A	12	N/A	50	N/A	18	N/A
Sixth St	19	N/A	2	N/A	11	N/A	47	N/A	21	N/A

*N/A indicates that sample was not taken, "-" sampling was not possible during pre-period due to the culvert

Fish Species by Location and Time Period (courtesy of NH Fish and Game)

	Total Fish		Fallfish		American eel		White Sucker		Hatchery Brook Trout		Common Sunfish	
Site	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Ash St.	1	1	0	0	0	0	1	0	0	0	0	1
Hough St.	16	29	10	20	2	3	4	0	0	0	0	6
Sixth St.	10	24	5	13	1	0	1	3	2	2	1	6



%IC, EPT taxa richness, Total abundance vs. Location and Time
(%IC)
0
5
10
15
20
25
30
35
EPT taxa richness
0
5
10
15
Total abundance
0
1000
2000
3000
4000
5000
6000
Exeter River
Fordway Brook
Towle Brook
Parting Brook
Parkman Brook
Reservoir Brook
College Brook
Berry Brook
Hodgson Brook
Paul Brook
College Brook
Sixth
Hough
Maple
Roosevelt
Stream Restoration
Maple.
College Brook.
Pre
Pre
Post
USGS
UNH
Sampled By / Time / Site

Conclusions

Macroinvertebrates

As shown in the above figure, total abundance and EPT taxa richness are significantly lower as compared to the reference reaches. At this time it is suspected that macroinvertebrate populations have not had time to respond to the changes and improvements in the Berry Brook Watershed considering reproduction cycles and time of year. This data does improve our understanding of the macroinvertebrate populations and potential variability in Berry Brook. Continued long-term macroinvertebrate sampling and analysis is essential in determining the effects of the restoration activities.

Fish

Overall fish populations did improve in the post construction period at two of the locations. It should be noted that data collection times were very different for pre and post (May and October). Typically fish-IBIs are not calculated on sample results that contain less than 30 individuals. Consequently, Berry Brook falls into that category for all of its locations. This data does improve our understanding of the fish populations and potential variability in Berry Brook. Continued long-term fish counts are essential in determining the effects of the restoration activities.

Appendix E – Model

This section is intended to provide supplemental modeling information to Section 2.3.5 and 2.3.6. A table of model input variables, descriptions, sources for initial values and whether the parameter was calibrated is shown below. Many of the initial values were obtained from GIS delineations and UNHSC field verification. For the variables such as groundwater initial values were based on program defaults and tools. The most powerful calibration variables included soil conductivity, impervious area, and average junction inflow. Effective impervious area was field measured with a linear regression of direct runoff vs. rainfall and as a result not calibrated. Soil conductivity initial values were based on areal weighting of hydrological soil groups, this variable was calibrated due to the high level of spatial uncertainty with pervious soils. Conductivity was based on typical values by hydrologic soil groups (Akan and Houghtalen 2003). Average junction inflows were also powerful parameters that were initially based on field measured values. Baseflow is a dynamic parameter that changes with seasons and climate. Ideally, a monthly time pattern could be applied to adjust for this variation. Due to the duration of monitoring ~4 months for pre_{UD} and $post_{UD}$ this approach could not be used as the period does not represent an entire year. Average baseflow was optimized as one value for the entire calibration period. As a result there are times that baseflow modeled values exceeds observed and vice versa. Calibration results on a per storm basis and overall fit for peak and total volume are shown below.

Calibration Parameters

Variable	Variable Description	Initial Value	Cal
Subcatchments			
Area	Area of subcatchment (acres)	GIS	No
Width	Width of overland flow path for sheet flow runoff (ft)	GIS	Yes
Imperv	Percent of land that is directly connected impervious area	Rainfall-runoff relation	No
Slope	Average percent slope of the subcatchment	DEM	No
N Imperv	Manning's n for overland flow over the impervious portion	Literature	No
N Perv	Manning's n for overland flow over the pervious portion	Literature	Min
Dstore Imperv	Depth of depression storage on the impervious portion of the subcatchment (inches)	Default	Min
Dstore Perv	Depth of depression storage on the pervious portion of the subcatchment (inches)	Default	No
Zero Imperv	Percent of the impervious area with no depression storage	Default	No
Subarea Routing	Choice of internal routing of runoff between pervious and impervious areas	Field Verification	No
Percent Routed	Percent of runoff routed between subareas.	Field Verification	No
Infiltration: Green-Ampt			
Suction Head	Average value of soil capillary suction along the wetting front (inches)	Default	Min
Conductivity	Soil saturated hydraulic conductivity (in/hr)	GIS: HSG's	Min
Initial Deficit	Difference between soil porosity and initial moisture content (a fraction). The initial deficit for a completely drained soil is the difference between the soil's porosity and its field capacity.	Default	Min
Ground Water - Formula	$Q_{GW} = A1(H_{GW} - H^*)^{B1} - A2(H_{SW} - H^*)^{B2} + A3(H_{GW} H_{SW})$		

GW Flow Coeff.	Value of A1 in the groundwater flow formula	Default-Wizard	Yes
GW Flow Expon.	Value of B1 in the groundwater flow formula	Default-Wizard	Yes
SW Flow Expon.	Value of A2 in the groundwater flow formula	Default-Wizard	Yes
SW Flow Coeff.	Value of B2 in the groundwater flow formula	Default-Wizard	Yes
Conduits			
Length	Conduit Length (ft)	GIS	No
Roughness	Manning's roughness coefficient	Literature	Yes
Geom1	First geometric dimension of the conduits cross-sectional shape	GIS/Field Survey	No
Cross-Section	Cross-section of irregular shape conduits	Field Survey	No
Junctions			
Invert El.	Invert Elevation of the junction (ft)	Field Survey	No
Average Value	Specifies the average (or baseline) value of the dry weather inflow (ft)	Hydrologic Observation	Yes
Storages			
Invert El	Invert elevation of the storage unit (ft)	GIS/Field Survey	No
Depth	Depth of the storage unit (ft)	GIS/Field Survey	No
Ponded Area	Area occupied by ponded water atop the storage unit after flooding occurs (sq.ft)	GIS/Field Survey	No
Weir			
Discharge Coeff.	Discharge coefficient for flow through the central portion of weir	Literature	Yes
Water Quality			
Land Use & EMC	Event mean concentration based on pollutant type and land use	Literature	Yes

Calibration Results

This section is intended to provide specific examples of model vs. observed agreement for specific storms of all three scenarios (Pre_{model}, LID_{model}, EIC_{model}) and overall fit of total volume and peak flows. Each plot provides goodness of fit statistics to represent model vs. observed agreement. The hydrographs for each scenario are examples of final calibration where (obs) represents the observed or field measured values. The Calibration Storms section represents a plot of modeled/computed vs. observed. A perfect agreement of modeled and observed would plot on a 1:1 line. In our case calibration was based on the optimization of total volume and peaks adjusting the parameters described in Calibration Parameters. Peak flow and volume were chosen based on modeling objectives which was largely focused on these parameters

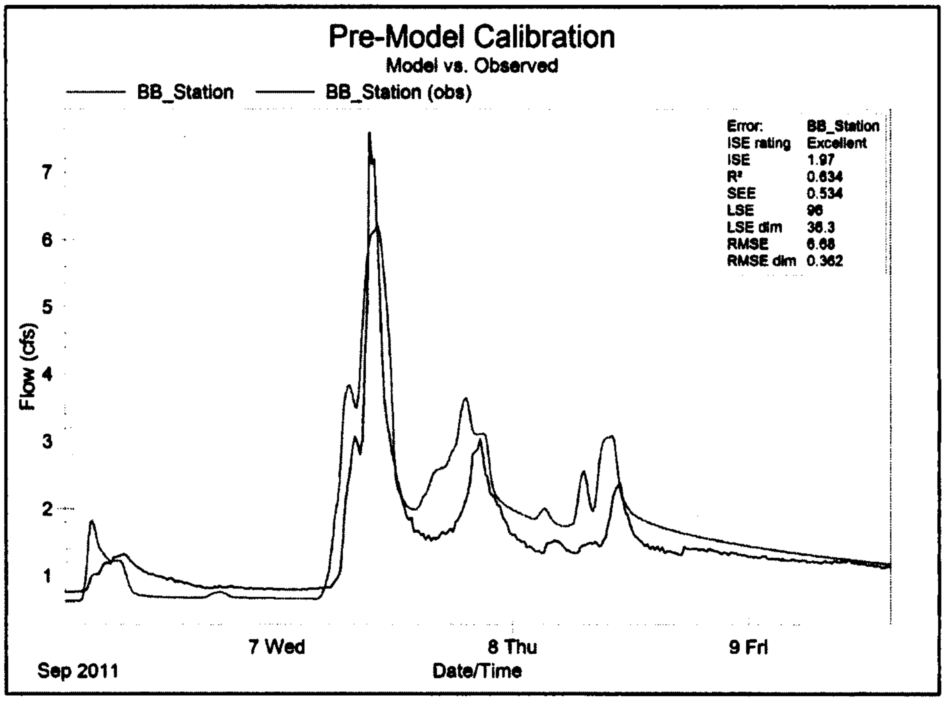
Water quality model calibration on storm event pollutant loads was done as manual iterations for the Pre_{model}. Pollutant EMC was used as the calibration variable optimized by percent error between modeled and observed values shown below.

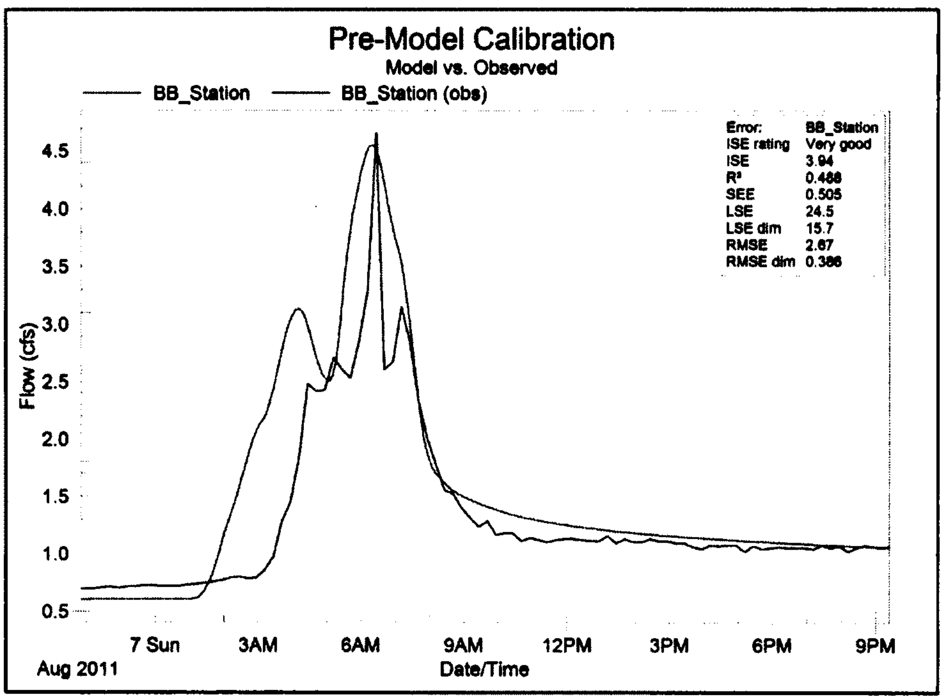
Water Quality Calibration Results

	TSS (kg)			TN (kg)			TP (kg)		
Storm	**Obs**	**Mod.**	**%Error**	**Obs**	**Mod.**	**%Error**	**Obs**	**Mod.**	**%Error**
1	505	520	-3.0	9.6	13.5	-40.6	0.87	0.93	-6.9
2	91	133	-46.2	1.64	1.73	-5.5	0.19	0.24	-26.3

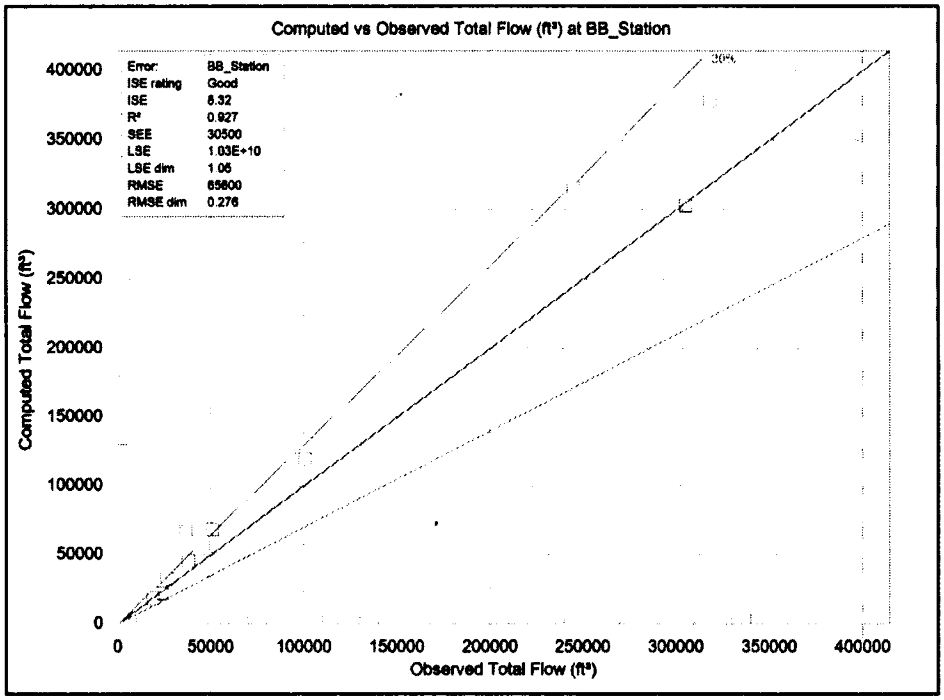
*Mod. = model results, Obs. = observed/field measured

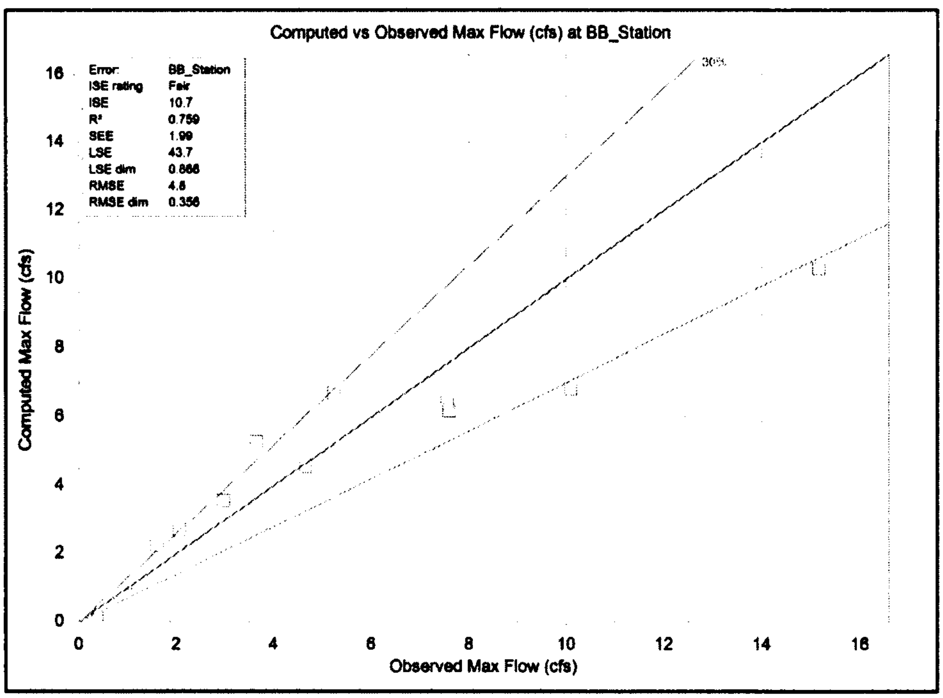
Pre$_{model}$-Hydrographs



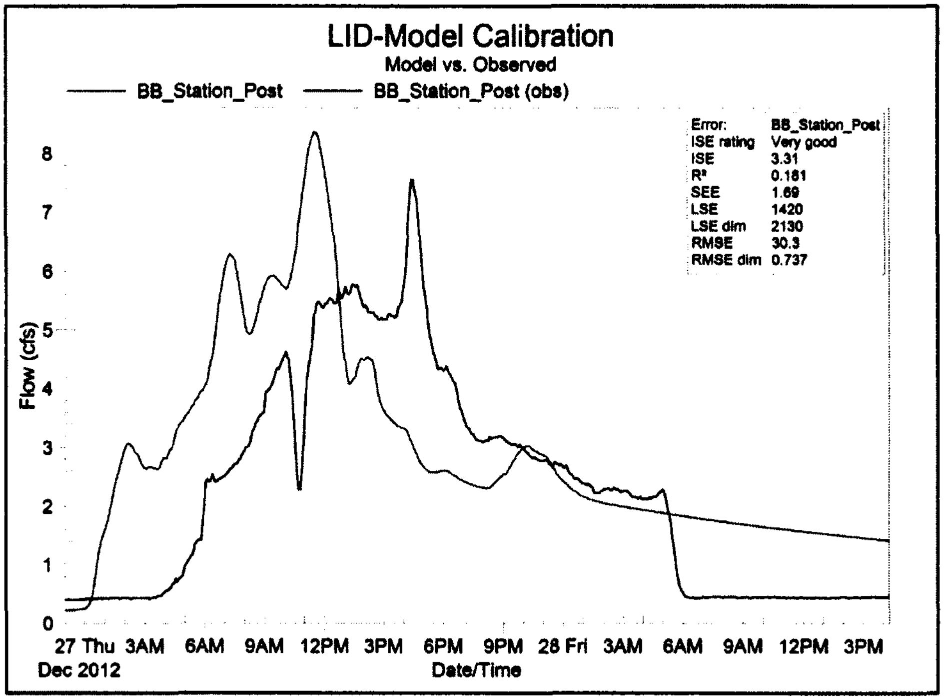


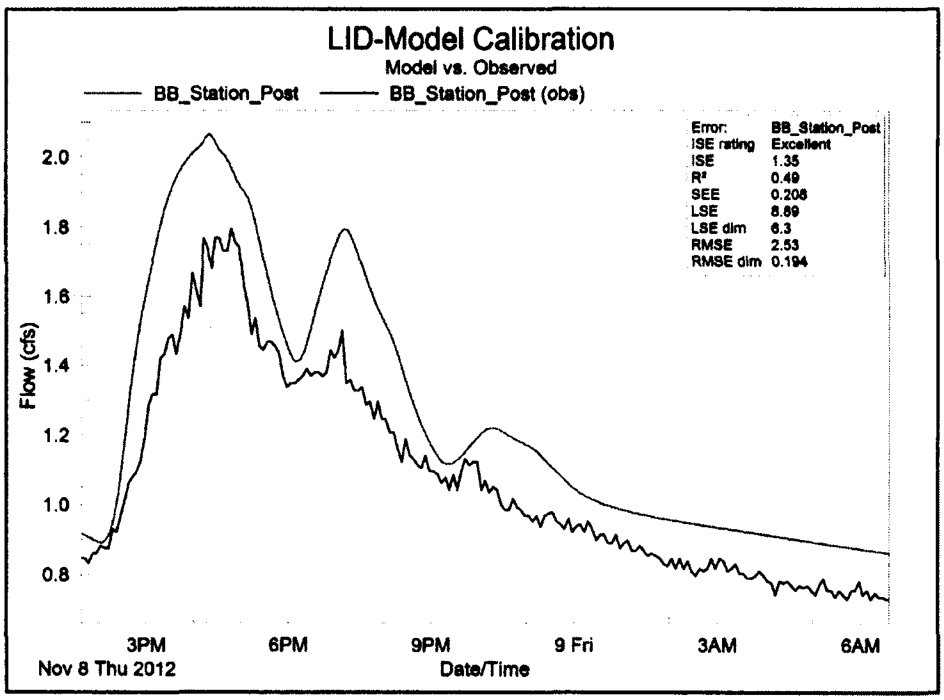
Pre$_{model}$-Calibration Storms



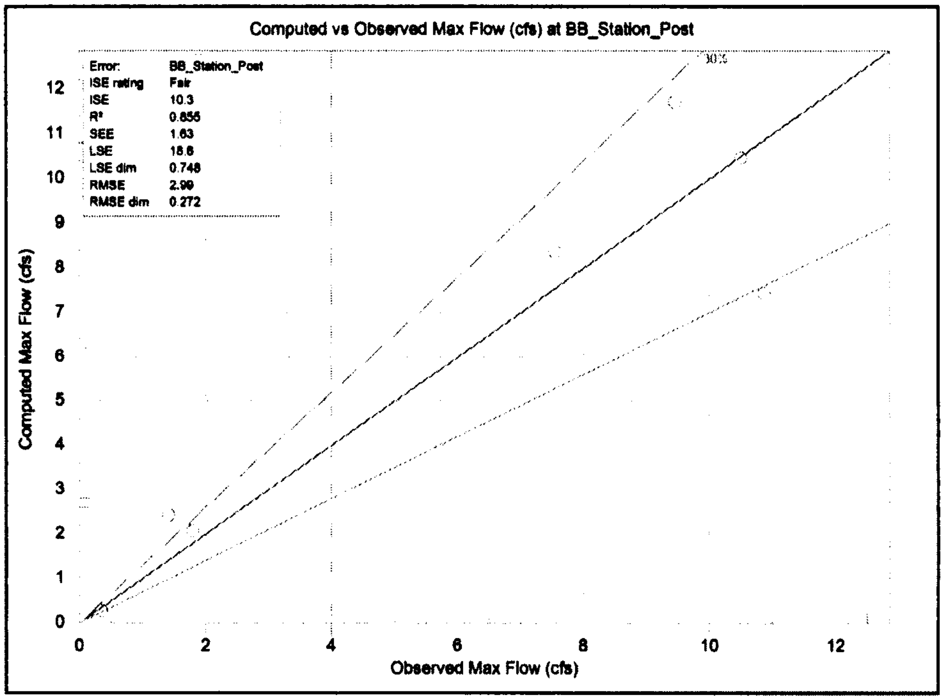


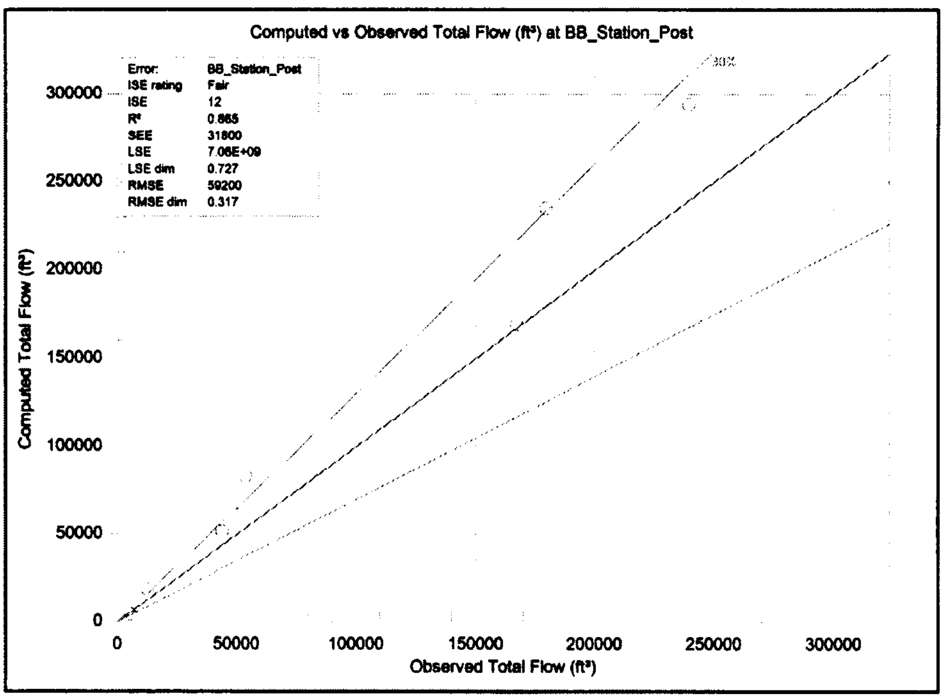
LID$_{model}$-Hydrographs



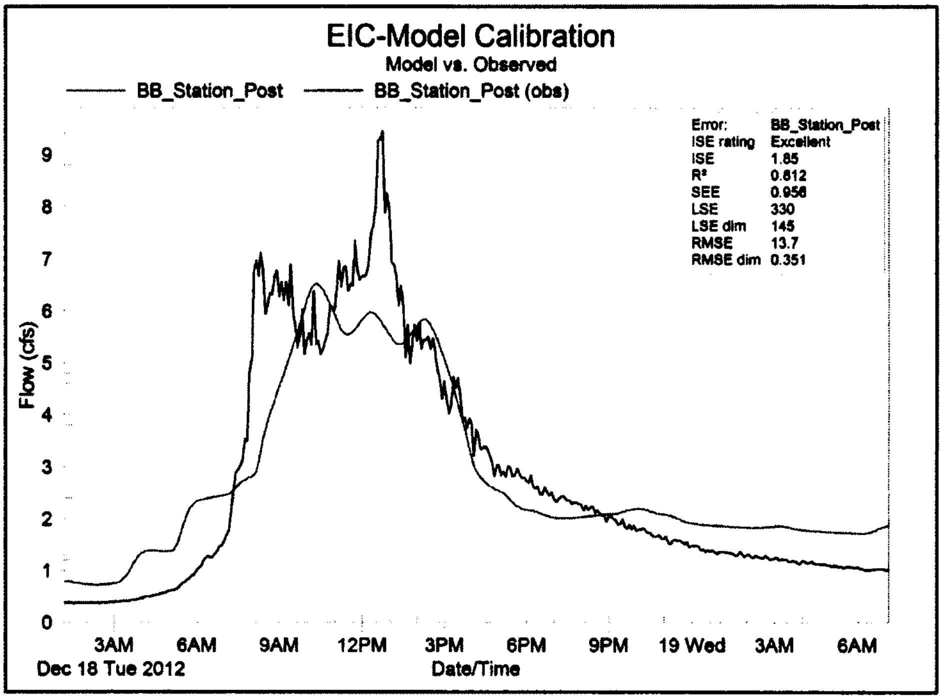


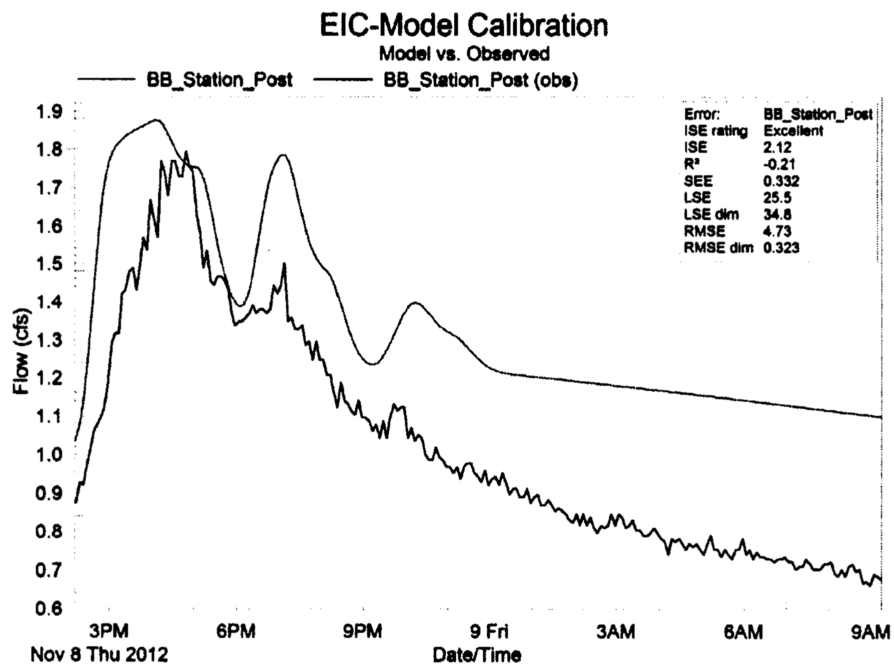
LID$_{model}$-Calibration Storms



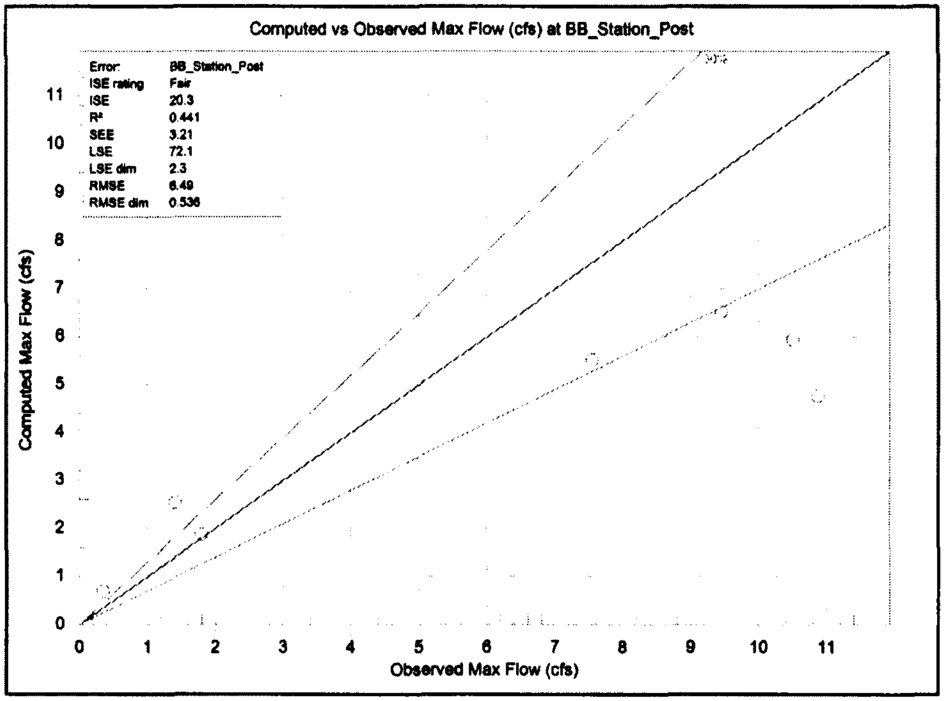


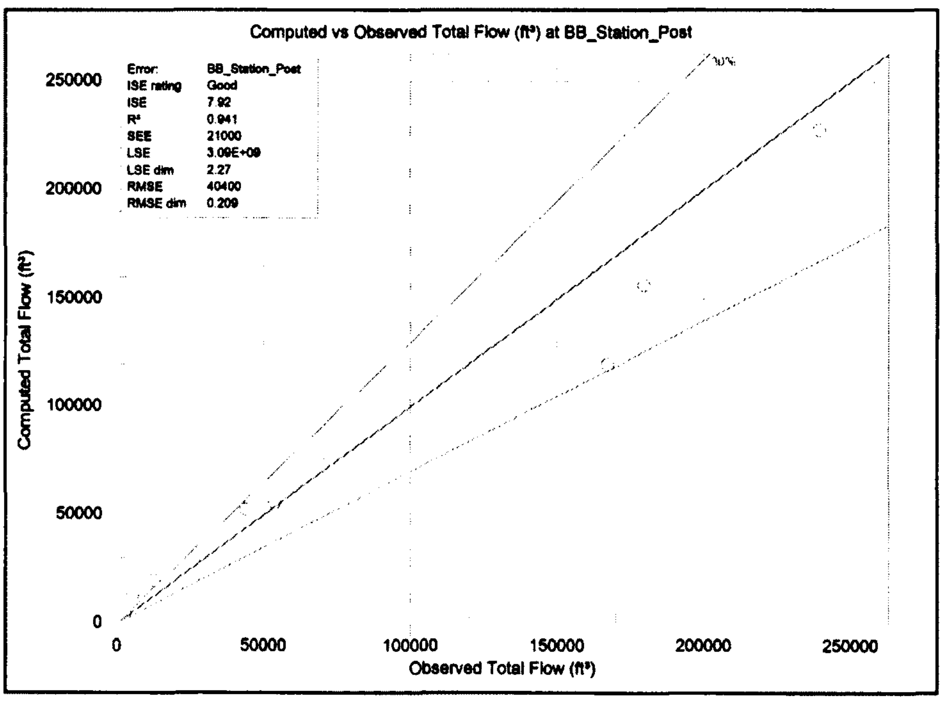
EICmodel-Hydrographs





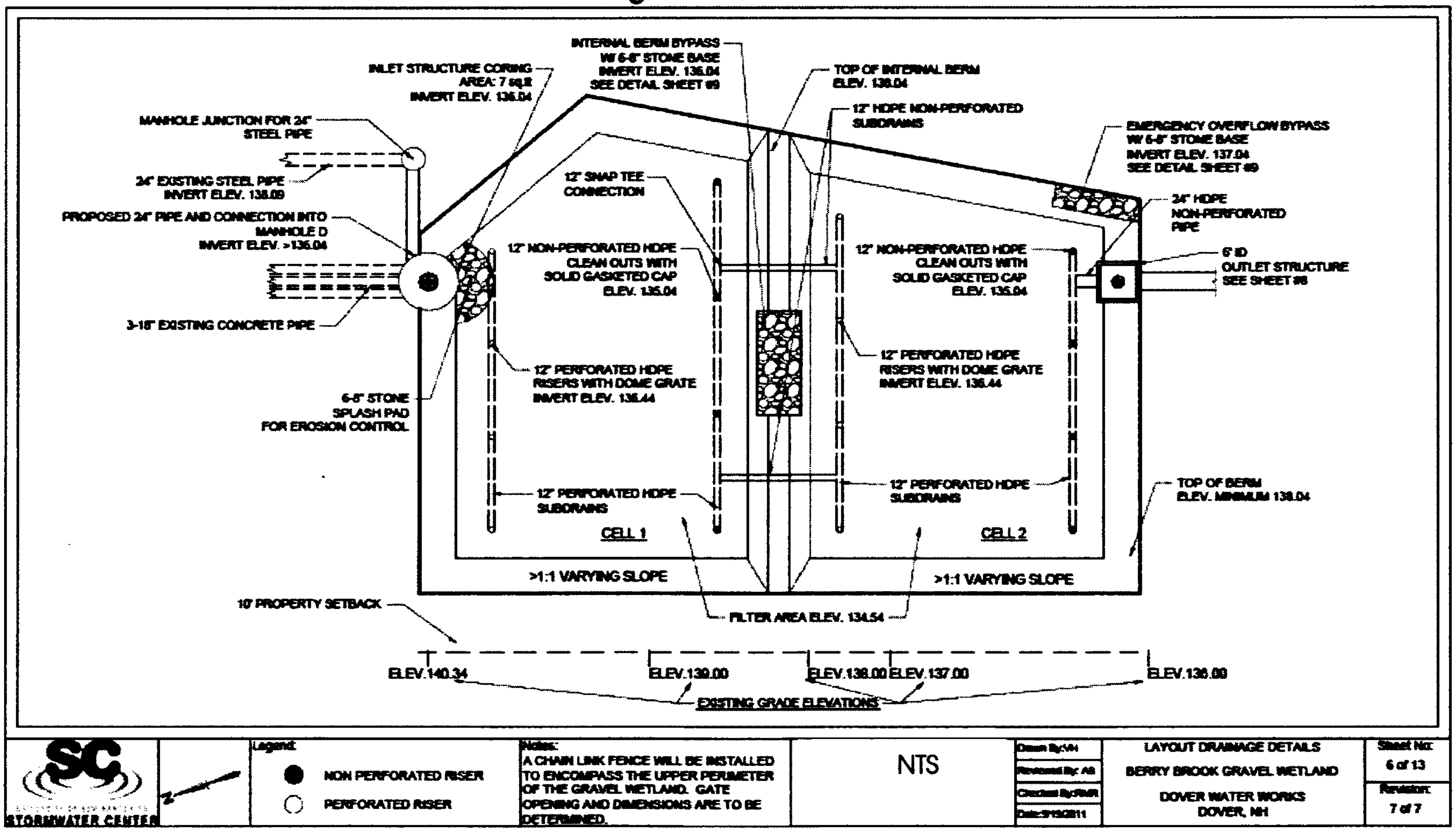
EIC_{model}-Calibration Storms



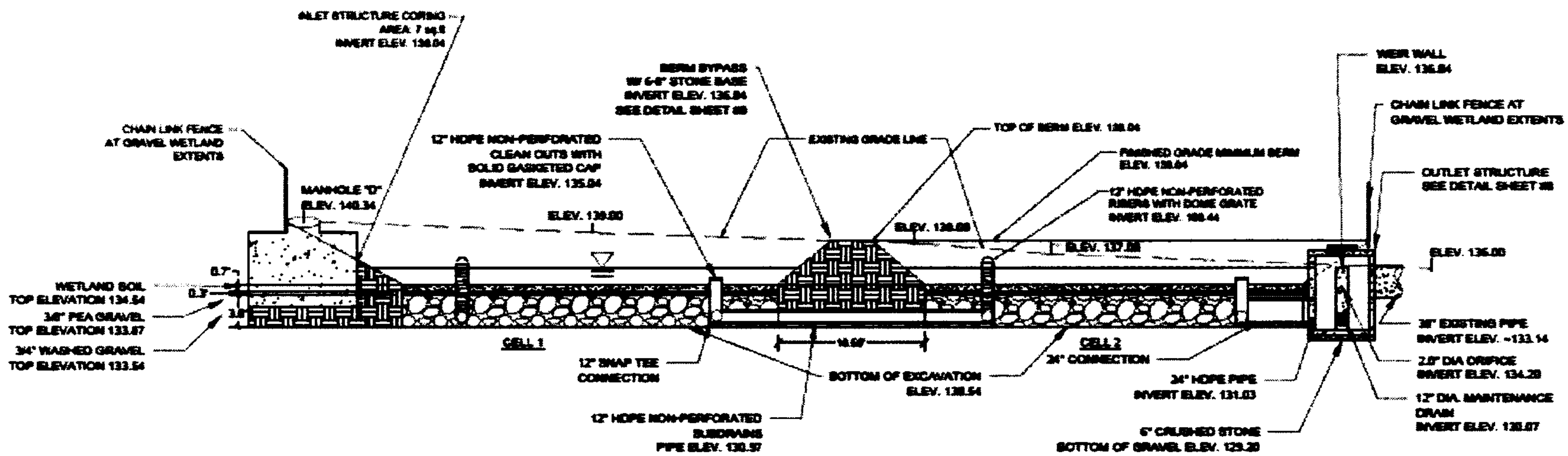


Appendix F - LID Drawings

Central Ave. Subsurface Gravel Wetland Design Plan View



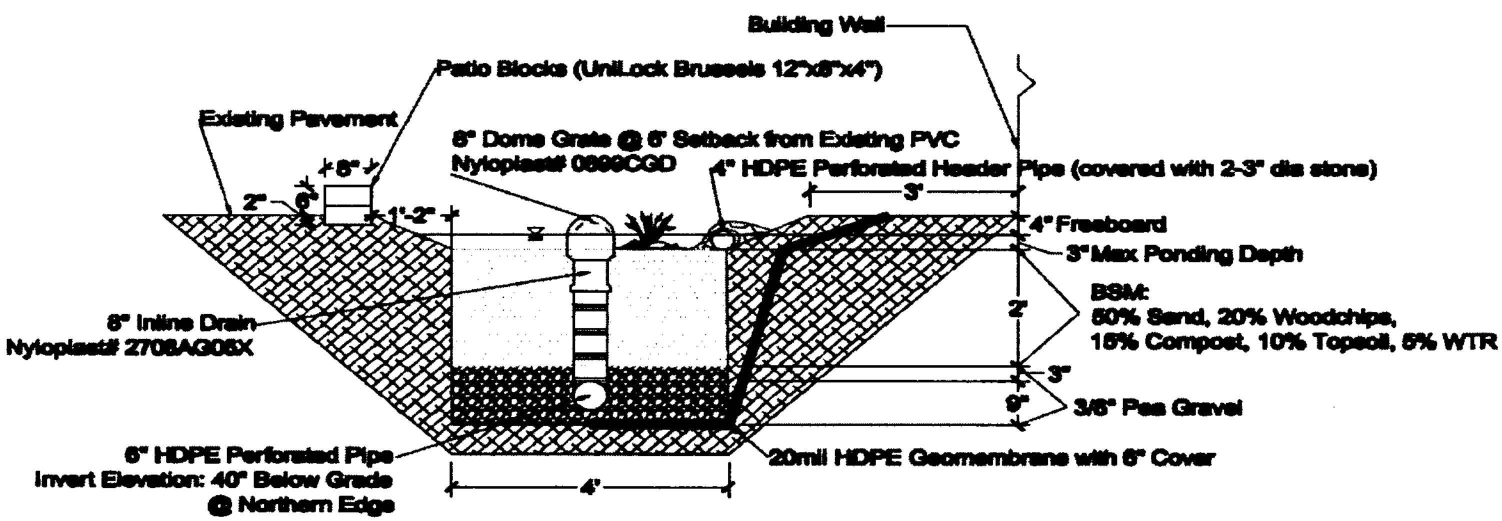
Central Ave. Subsurface Gravel Wetland Profile View



STORMWATER CENTER		Legend:	Notes: EXISTING ELEVATIONS FROM FIELD SURVEY BY UNHSC	NTS	Drawn By:VH Reviewed By:AB Checked By:RMR Date:9/15/2011	LONG SECTION ELEVATION DETAIL BERRY BROOK GRAVEL WETLAND DOVER WATER WORKS DOVER, NH	Sheet No: 7 of 13 Revision: 7 of 7

124

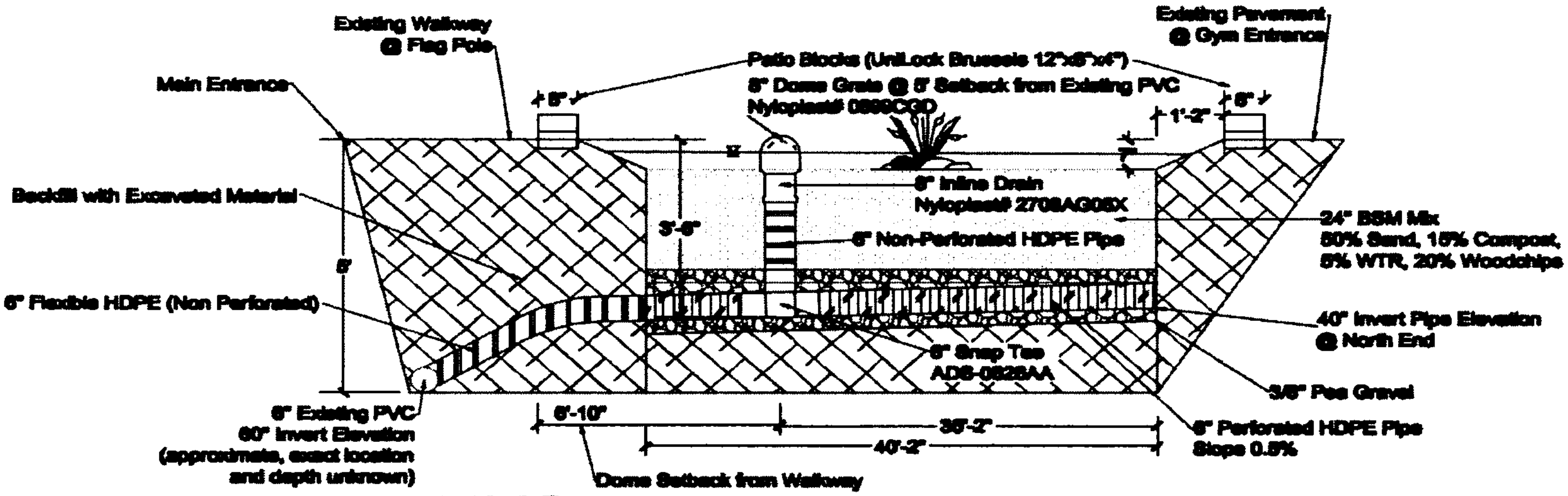
Home Street School Bioretention System Cross Section



Notes:
1-800-DIGSAFE

UNIVERSITY OF NEW HAMPSHIRE STORMWATER CENTER		NTS	Drawn By: VH	Bioretention Cross Section	Figure No: 3 of 4
			Reviewed By: JJH	Home St. School	
			Checked By:RMR	78 Home St., Dover NH,03824	Revision: 4 of 4
			Date: 5/18/2011		

Home Street School Bioretention System Profile View



NTS

Notes:
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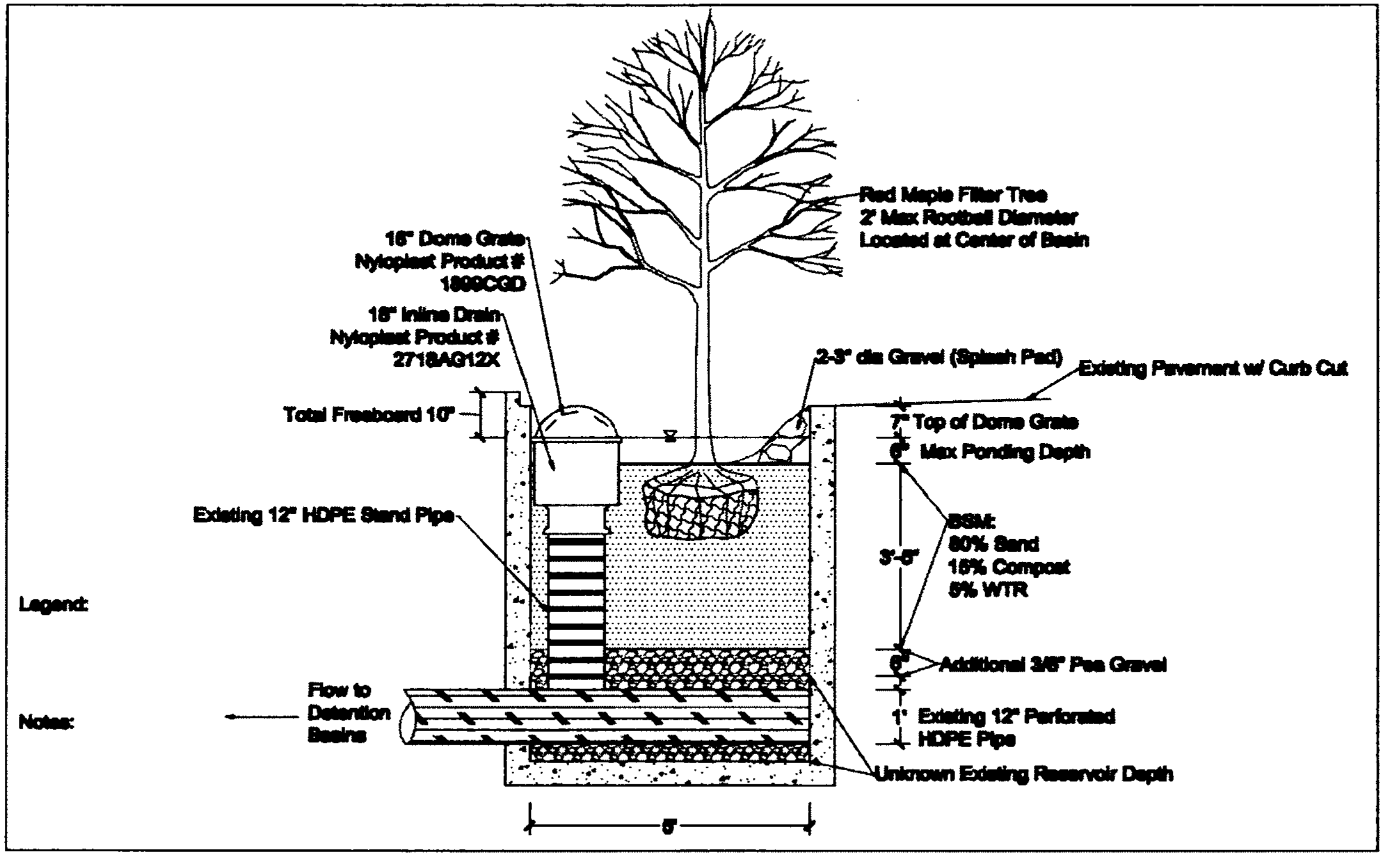
UNIVERSITY OF NEW HAMPSHIRE STORMWATER CENTER		Scale NTS	Drawn By: VH Reviewed By: JJH Checked By:RMR Date: 6/17/2011	Bioretention Pipe Detail Home St. School 78 Home St., Dover NH,03824	Figure No: 4 of 4 Revision: 5 of 5

Home Street School Tree Filter



UNIVERSITY OF NEW HAMPSHIRE STORMWATER CENTER		NTS	Drawn By: VH Reviewed By: JJH Checked By: RMR Date: 8/12/11	Tree Filter Cross Section Home St. School 78 Home St., Dover NH, 03820	Figure No: 1 of 1 Revision: 3 of 3